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GENERAL ZOOLOGY

BY

A. S. PEARSE

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To My Wife

WHO, THOUGH WHOLLY UNSCIENTIFIC,
HAS LOYALLY DEVOTED FIFTEEN
YEARS TO THE ADVANCEMENT
OF SCIENCE

PREFACE

This book has been written to be read by students of eighteen to twenty years of age. With this in mind the chapters have been made short, and an attempt has been made to enliven the text by interpolating a considerable number of illustrations that lean more toward natural history than anatomy.

The purpose of the book is to give a general survey of the important points relating to the chief groups of animals. The first four chapters deal largely with generalities and may well follow chapters which come later if such an arrangement is more expedient for any particular course. An important place is given to insects because they afford the most available material for collecting, classification, and dissection—students can acquire a variety of first-hand knowledge from them as from no other group of animals.

The writer is convinced that students of biology get the best training in scientific methods of thought from practical work, and that it should constitute the chief part of any course; also that a text-book should not repeat what is observed in laboratory or field, but supplement and generalize upon such information. The book ought, therefore, to contain more of natural history and general biological theory than anatomy. Some chapters in the present work (*e.g.*, X) are perhaps without much unity or apparent purpose, and are intended primarily to serve for reference in connection with laboratory or field studies.

Anyone who teaches is stimulated by association with great teachers—men of originality who are scientific, yet human, and who are ever willing to help or encourage students. Though this book intends to be original, the writer is fully aware that he has consciously and unconsciously used the ideas of others. Foremost among those

who have thus unwittingly contributed are: G. H. Parker, W. C. Curtis, and M. F. Guyer.

In the preparation of the book the writer has been under obligation to a number of persons, and it is a pleasure to acknowledge the debt. Professor M. F. Guyer read the manuscript for chapters I to V, XXVII, XXVIII, XXX, and helped in other ways; Professor George Wagner, read chapters XI to XX; Professor W. S. Marshall, V to XI; Professor W. J. Meek, XXVII; Dr. John N. Lowe, I to IV; Miss G. M. White, XXI and XXII; Messrs. A. R. Cahn and T. C. Nelson, XXV and XX respectively. Dr. A. G. Ruthven and Professor E. C. Case, of the University of Michigan, read chapters XXIII, XXIV, XXVI and XXIX. Most of all I am indebted to Miss Hattie J. Wakeman, who drew all the original figures but two. Fig. 46 was drawn by Lydia Wakeman, and Mr. A. R. Cahn furnished the prints for Fig. 103.

University of Wisconsin,
March 1, 1917.

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GENERAL ZOOLOGY

CHAPTER I

THE ABUNDANCE OF ANIMAL LIFE

Most persons do not realize what an enormous number of animals exist on the earth, and what a variety of habitats they occupy. The forest not only harbors monkeys, squirrels, tree frogs, and other familiar animals which are suited to such a situation, but also supports a host of minute insects, worms, snails, and other things which escape ordinary notice. Many of these are active only at night, on humid days, or on various infrequent occasions. The fields and prairies have a characteristic fauna of prairie-dogs, grasshoppers, antelope, etc. Lakes, ponds, and streams swarm with aquatic animals. Particularly in winter, bodies of water serve as refuges for many animals which may be found elsewhere during warmer seasons. Some animals, such as the mole, the mole-cricket, and the earthworm, pass their whole lives burrowing in the soil, and show structural adaptations which fit them particularly for such a habitat.

Unsuspected residents may occur in all sorts of situations and in countless numbers. Darwin was once interested in the distribution of animals and plants on the feet of birds. In this connection he tried to ascertain how many living things there were on the muddy shore of a little puddle. From three spoonfuls of mud he raised 537 separate plants. More recently one of the investigators for the United States Department of Agriculture, in studying the food of birds, took a census of all the animal and plant objects in a space two feet square and as deep as a bird might scratch, with the following result:

	Animal objects	Plant objects
Forest	112	194
Meadow	1254	3113

Probably most readers have never heard of nematode worms, yet Cobb in a paper on these animals says:

"Not the least interesting thing about nematodes is the astounding variety of their habitats. They occur in arid deserts, at the bottoms of lakes and rivers, in the waters of hot springs and in polar seas where the temperature is constantly below the freezing point of fresh water. They were thawed out alive from Antarctic ice in the far south by members of the Shackleton expedition. . . . A thimbleful of mud from the bottom of river or ocean may contain hundreds of specimens. The nematodes from a 10-acre field, if arranged in single file, would form a

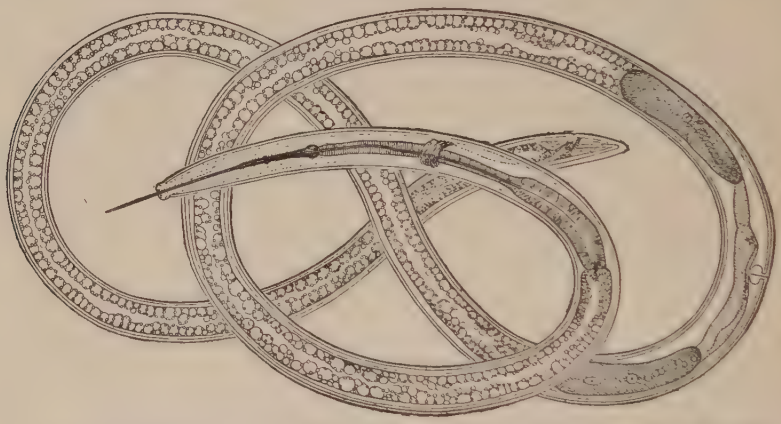


FIG. 1.—A nematode worm which lives on the roots of plants. Greatly magnified. (*From Cobb, Yearbook; U. S. Department of Agriculture*, 1914.)

procession long enough to reach around the world. A lump of soil no larger than the end of one's thumb may contain hundreds, even thousands of nematodes, and yet present few points that would distinguish it from a lump of soil destitute of these organisms. . . . In short, if all other matter in the universe except the nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes, and oceans represented by a film of nematodes. The location of towns would be decipherable, since for every massing of human beings there would be corresponding massing of certain nematodes. Trees would stand in ghostly rows representing our streets and highways."

Instances of this kind might be multiplied. There are animals in the soil which even exceed the nematodes in numbers.

DEFINITIONS

Biology is the branch of natural science which includes all studies pertaining to living things. There are two great subdivisions: Botany, which deals with plants; and Zoology, which is concerned with animals. *Zoology*, then, is the body of facts and theories derived from the scientific study of animals. Our science is founded on facts, and over this superstructure there have been erected a number of theories which are intended to blend zoology into a harmonious whole. We must be scientific in our study. This is the hardest task a zoologist has from day to day. A scientist's aim is to discover the truth about phenomena. A real scientist formulates his conclusions and general laws from a study of the available facts, and he does this without prejudice, or superstition, or thought of self interest. Let us be scientific! This means accurate observation and sound, thoughtful conclusions.

On account of the amount of material which has been accumulated from zoological studies, men's interests have been divided and a number of subsciences established. Chief among these are the following:

Systematic Zoology deals with the description of species and their classification according to accepted systems. About 522,400 species have been described, and the mere cataloguing of these requires considerable work by specialists. There are many branches of systematic zoology, such as: *entomology*, relating to the classification of insects; *ornithology*, birds; *conchology*, molluscs, etc.

Distributional Zoology has two aspects. Under *Zoogeography* are included facts relating to the present arrangement of animals on the earth. Five great realms which possess characteristic animals are recognized (Holoarctic, African, Indo-Malayan, Neotropical, Australian), and these have each been subdivided into smaller parts. *Paleozoology* deals with the distribution of animals during

the past, as shown by fossil remains. Zoogeography, then, has reference to space; Paleozoology, to time.

Morphology is the science of structure. *Anatomy* deals with dissection; *embryology*, with the changes which take place as individuals develop to maturity; *histology*, with minute anatomy or the study of tissues; *pathology*, with the structure of diseased tissues; *neurology*, with the make up of nerves; *paleontology*, with the characteristics of fossil animals.

Physiology treats of the functions of the parts of animals —*i.e.*, how the structures which make up the mechanism of any animal work. As under morphology there are a number of subdivisions: *psychology* is concerned with the working of the mind; *psychiatry*, with the operations of diseased or abnormal minds.

Ecology considers the relations of animals to their environment. Here would properly come such topics as the relations of parasites to their hosts, colonial habits, the denizens of particular habitats, etc.

Evolutionary Zoology relates to the origin and descent of species. *Heredity* is concerned with how characteristics are transmitted from parent to offspring. *Eugenics* deals particularly with heredity in man, with the aim of improving the human race.

SHORT HISTORY OF ZOOLOGY

If we are going to be zoologists, even in a small way, it is fitting that we should know something about those who have laid the foundations of our science. The following ten names have, therefore, been selected to serve as "milestones of zoological progress."

ARISTOTLE, the "Father of Natural History," was a Greek scholar who lived from 384 to 322 B.C. He wrote in all about three hundred works on philosophy, metaphysics, psychology, and rhetoric, but his most noteworthy writings were in the field of natural history. His greatest

contribution to zoology was his method of study. He gathered first-hand knowledge about animals and presented his facts in a scientific way. Locy says, "the influence of Aristotle was in the right direction. He made a direct appeal to nature for his facts, and founded his Natural History only on observation of the structure, physiology, and development of animals." Aristotle's best books, the "History of Animals," the "Parts of Animals," and the "Generation of Animals," were authoritative for twenty centuries. Aristotle led an active public life, being a student of Plato and a teacher of Alexander the Great.

FIG. 2.—Aristotle. (*From Locy, Biology and Its Makers.*)

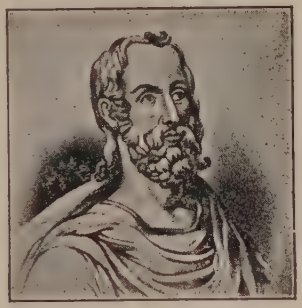


FIG. 3.—Pliny. (*From Locy, Biology and Its Makers.*)

PLINY, 23–79 A.D., was a Roman general and writer. He wrote thirty-seven voluminous and uncritical volumes on natural history. His works were filled with tales of dragons, gorgons, and other fabled monsters, so that it was impossible to separate fact from fiction. His influence was highly detrimental to the progress of zoological thought, but his works, nevertheless, were authoritative during the middle ages.

GALEN, 130–200 A.D., was a Greek physician. He was the great anatomist of antiquity and his clear and forceful descriptions were the sole anatomical guides in the medical schools for twelve centuries after his time. He was a sound thinker and accurate observer. Galen probably never actually dissected the human body, but wrote his

excellent works from studies and comparisons of other animals.

During the *Middle Ages* there was no progress in zoological thought. All questions were referred to ancient authorities. Matters of learning were almost wholly in the hands of the clergy, who deemed everything unworthy which did not pertain directly to religious life. The admonition to "shun the world" was taken all too seriously by the early Christians. There was stagnation in all fields of learning.

FIG. 4.—Galen. (*From Locy, Biology and Its Makers.*)

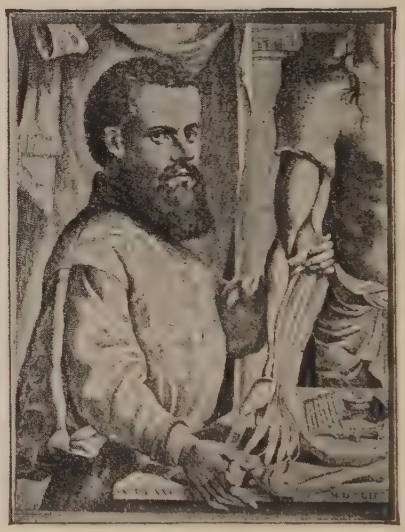


FIG. 5.—Vesalius. (*From Locy, Biology and Its Makers.*)

VESALIUS (1514–1564, Belgian), more than any man, threw off the yoke of tradition and the respect for authority which had characterized the scholars of the Middle Ages and opened the way for the free discovery of new knowledge which we enjoy today. He was a man of great courage and honesty. Despite the superstitious traditions of his time, he dissected the human body. His eminent book, the "Structure of the Human Body," and his direct methods

of teaching revolutionized anatomical methods. His greatest work, however, was the opening of men's minds to the opportunities for scientific progress to those who would make observations for themselves and draw their own conclusions.

HARVEY (1578–1667, English), following the anatomical discoveries of Vesalius, laid the foundations of our modern methods of experimental investigation in biological science. His great work was the demonstration of the circulation of the blood, an epoch-making discovery. Before his time it was supposed that there was a sort of an ebb and flow

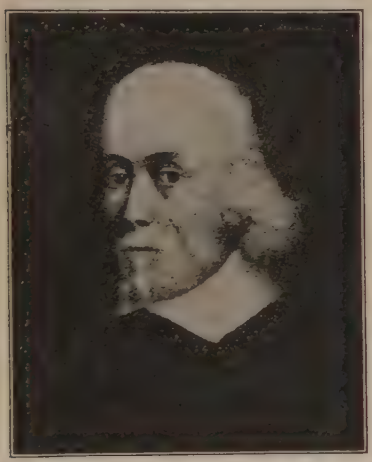


FIG. 6.—Harvey. (*From Locy, Biology and Its Makers.*)

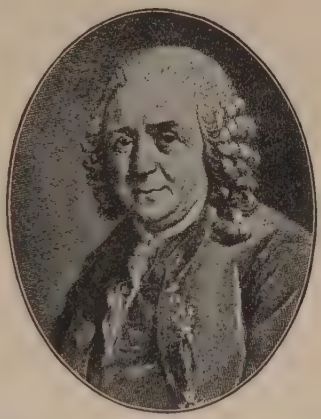


FIG 7.—Linnaeus. (*From Locy, Biology and Its Makers.*)

in the blood-vessels, that the arteries contained blood mixed with animal spirits from the lungs, and that the veins held the crude blood. Harvey showed conclusively that the blood traversed a regular route through the body. This may seem like a simple everyday fact at the present time, but in the fifteenth century Harvey's assertions, though they were finally accepted, excited great controversy and astonished the whole scientific world.

LINNAEUS (1707–1778) was the founder of modern systematic zoology. Before his time species were rather

indefinitely known from verbose Latin descriptions. This great Swedish naturalist inaugurated our present binomial nomenclature, giving to each species a scientific name consisting of two words, the genus and species. He attempted to describe and catalogue all species of plants and animals. In the tenth edition of his great work, the *Systema Naturæ*, 4236 species of animals were described. The general classification instituted by Linnaeus was not very satisfactory and has now been considerably amplified. In his later life Linnaeus was a professor in the University of Upsala and the foremost figure in the zoological world. His influence made classification and naming new species the most studied fields of biology for some time after his death.

Fig. 8.—Cuvier. (*From Locy, Biology and Its Makers.*)

Cuvier (1769–1832) was an eminent educator, being director of the higher institutions of learning under Napoleon Bonaparte. Early in life he conceived the idea of making a very comprehensive study of comparative anatomy and was so successful that this subject became the leading field of zoology until the time of Darwin. He also made very thorough studies of the anatomy of all the chief groups of animals which had existed in bygone ages. Cuvier would not accept the idea of an evolution of animals, but believed the earth had been repopulated again and again after a series of "catastrophisms" which wiped out everything alive.

Darwin (1809–1882) was an Englishman who received most of his zoological training during a five-year cruise as naturalist on the ship Beagle, which made a voyage around the world. After his return to England, he began with great care to accumulate data for his theory of evolution.

This theory is well set forth in the "Origin of Species," published in 1859. His great work for Zoology, and the world, was to convince scientific men that there had been a change in the past—that one type of animal had evolved from a somewhat different preëxisting type. His theory involved four ideas: (1) More animals are produced than can find a place to live and hence there is a "struggle for existence;" (2) qualities tend to be transmitted unchanged from parent to offspring; but (3) there is always slight variation which may make one animal a little better than others of its own species; and (4) there may thus be a "survival of the fittest" in the struggle, which constitutes the

FIG. 9.—Darwin. (*From Locy, Biology and Its Makers.*)

FIG. 10.—Agassiz. (*From Locy, Biology and Its Makers.*)

"*natural selection*" through which Darwin supposed animals improved after a number of generations. This theory gave a wonderful impetus to all branches of scientific work because it opened a vast field for investigation by clearing men's minds of the idea that natural phenomena had always been and always would be as they are, and were, therefore, not open to experimental study.

AGASSIZ (1807–1873), though a Swiss by birth, is of particular interest to all American zoologists. He was a comparative anatomist of the school of Cuvier who came

to America when a young man and introduced the scientific methods of Europe into this country. Though he was the first to work out the close relation between the fossil record and the embryonic stages in the development of individual animals, he would never accept his discoveries as evidences of evolution, and died an opponent of Darwin.

Huxley (1825–1895), though primarily a student of fossil animals, did a great work along general zoological lines for all English-speaking people. More than any other zoologist he was able to talk and write in an understandable way to popular audiences. His contribution to zoological progress, then, was to popularize zoology and make general biological laws matters of common everyday knowledge.

Fig. 11.—Huxley. (*From Locy, Biology and Its Makers.*)

From this brief historical survey it is plain that zoology has not come about all at once. There has been a long struggle to accumulate facts and to make theories to fit them. No one nation, nor class of people has done the good work, but a host of fair-minded energetic workers have contributed to progress. One of the fine things about science is its method of work. There is no secrecy nor selfishness—only desire to discover truth at any cost. For science men have died of fever during explorations; carried on life-long struggles with poverty, superstition, or other obstacles; or been shunned by their fellows for advocating new ideas. But through the courage and inspiration of such workers zoology has gone forward; we are not yet at the end of our discoveries; new things are flashing into the light of knowledge almost every day.

THE CLASSIFICATION OF ANIMALS

At the present time there are about 523,000 species of animals known, with perhaps an equal number yet to be described. It goes without saying that such a number of distinct kinds requires some means of classification, if only for convenience in cataloguing. There are in general two systems of classification—natural and artificial. The first is the result of an attempt to show genetic, or blood, relationships; the second term is applied to any system of grouping which will enable one to bring animals together which show certain points of similarity, whether such characteristics are of fundamental importance or not. In times past the barnacles were classed with molluscs because they possessed a calcareous shell, but when their embryology was studied it was discovered that all the early stages were like those of crustaceans, and they have since been classified with other members of that group—such as crabs, lobsters, and water-fleas. The former classification for the barnacles was artificial, the latter, it is believed, is more natural. Systematic zoologists are continually striving for a perfect natural classification.

The animal kingdom is divided into smaller and smaller units just as a military regiment is divided into battalions, companies, platoons, squads, and individuals. The largest groups are called phyla, these are subdivided into classes, etc. In going from larger to smaller, the groups would be arranged as follows: Phylum, Class, Order, Family, Genus, Species.

Each species of animal is known by its scientific name, which consists of the name of its genus and its own particular species. Taking man as an example, we may classify him. He belongs to the species *sapiens* and the genus *Homo*. This genus also includes some other species of men, none of which are now living. The scientific name of man would be, *Homo sapiens* Linnaeus; the last word showing that Linnaeus first described this particular species.

The genus Homo is grouped with a number of others containing ape-like animals in the family Hominidæ, and this family in turn is one of those which make up the order Primates, including monkeys of all kinds. Primates is one of the orders of the class Mammalia, which includes all animals which have hair and suckle their young—such as bats, seals, whales, hoofed animals, cats, dogs, etc. The class Mammalia is one of half a dozen in the phylum Chordata, one of the primary divisions of the animal kingdom.

CHAPTER II

BASIS FOR THE CLASSIFICATION OF ANIMALS

If one is going to classify 600,000 different kinds of animals, it will be necessary to have some general plan for making large divisions which will include a considerable number of species having common characteristics. To

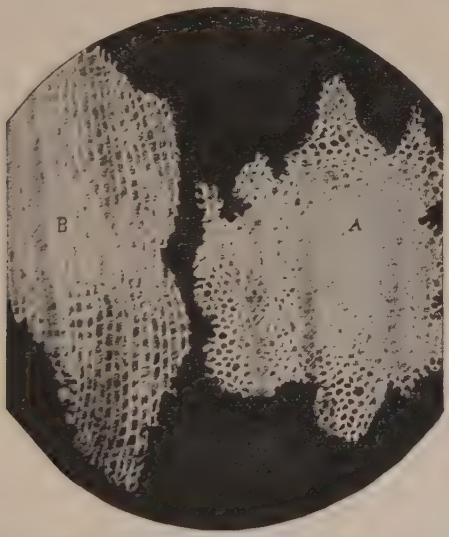


Fig. 12.—A bit of cork showing cells as represented by Hook, the discoverer of cells. (*From Locy, Biology and Its Makers.*)

make a natural classification the seven following criteria have been found of most value:

1. *Body Composed of One Cell or of Many.*—All living things are made up of little living units, the cells (Fig. 12), just as a brick house is made up of bricks. A cell, like a brick, may thus exist as part of a structure or as an independent unit. One great division of animals, Protozoa, is made by grouping all those together whose bodies are com-

posed of one single cell; another, Metazoa, by grouping together those whose bodies are multicellular.

2. *Diplo-* or *Triplo-blastic* (Fig. 13).—Animals made up of many cells show differences in arrangement. In the sponges the cells do not form layers but in other metazoans they form definite sheets. We may have, therefore,

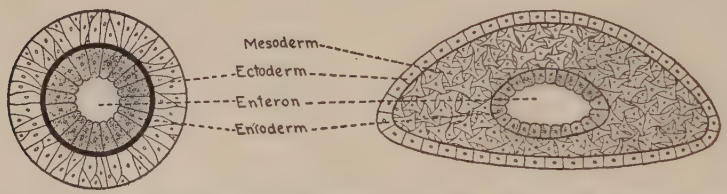


Fig. 13.—Sections across the bodies of Hydra and Planaria showing diploblastic and triploblastic structure. In the first there are two layers of cells between the digestive cavity and the outside; in the second, there are three.

diploblastic animals with two layers of cells—the ectoderm and entoderm; or *triploblastic* animals with three—ectoderm, mesoderm, and entoderm. These primitive sheets of cells which appear in the development of most Metazoa are called the *germ layers.*

3. *Body Metameric or Non-metameric* (Fig. 14).—The bodies of many animals show a condition of metamerism,

Fig. 14.—A slug and a leech, showing the absence and presence of metamerism. The slug has no subdivisions in the body, but in the leech the body is made up of a series of similar parts.

or segmentation. Similar parts are arranged one after the other and form a sort of a chain. Each of the segments has a more or less complete set of organs, and these are repeated in the successive segments of the body. Man

shows evidences of metamerism in the arrangement of his ribs, vertebræ, spinal nerves, muscles, etc. The common earthworm is a better example for its body is composed of a chain of very similar metameres.

4. *Symmetry Radial or Bilateral* (Fig. 15).—Some animals have the chief organs arranged around a central axis. The form is usually disc-like or spherical, perhaps also with projecting arms. In such radially symmetrical animals there are a number of *antimeres*, or body parts which might be interchanged without destroying the original symmetry, just as one could exchange two quarters of a pie without

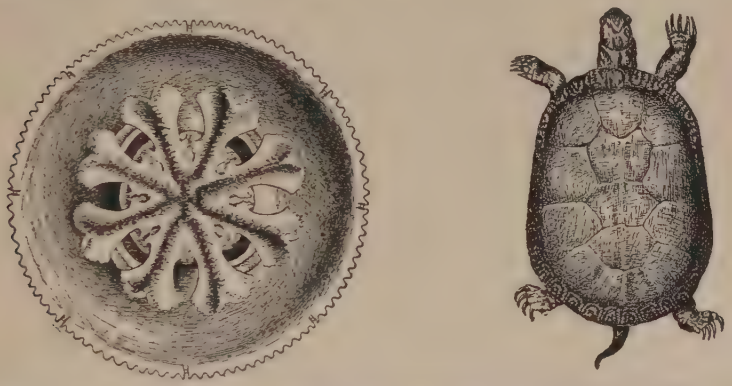


FIG. 15.—A jelly-fish and a turtle, showing radial and bilateral symmetry respectively.

spoiling its general shape. Jelly-fishes, corals, and star-fishes are examples. Those which grow fixed to some object have distal (free) and proximal (attached) ends; those which move freely have no "head" or "tail" end, but possess oral (mouth) and aboral surfaces. In bilaterally symmetrical animals, on the other hand, the body has a front or *anterior* end, which often is distinguished as a head. The opposite end is the *posterior* or hind portion; there are right and left sides; a *dorsal* or back, and a *ventral*, or belly side. Such animals are symmetrical on two sides of a plane which passes down the middle of the dorsal and ventral sides. The portions on either side of this plane are called

lateral. Man may serve as an example of a bilaterally symmetrical animal.

5. *Body Sac-like or a Tube Within a Tube, i.e., Acœlomate or Cœlomate* (Fig. 16).—Some animals, like the fresh-water

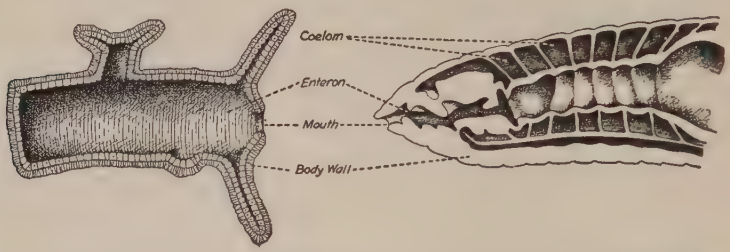


Fig. 16.—A Hydra and the anterior end of an earthworm. Both have been split lengthwise so that the inside of the body is exposed. The Hydra has only one cavity, the enteron, or digestive cavity; the earthworm has another cavity, the cœlom, between the digestive tube and the body wall.

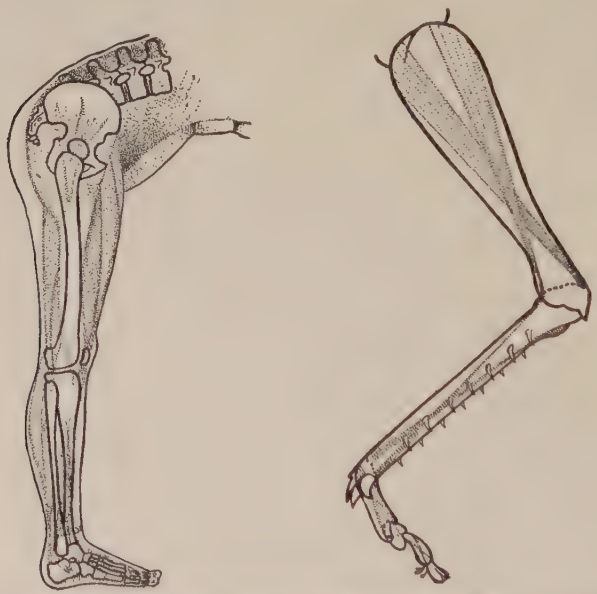


Fig. 17.—Showing endo- and exoskeletons. The bones in a man's leg are surrounded by muscles; the skeleton of a grasshopper's leg consists of tubes with muscles inside.

hydra, have only one cavity within the body and the outside wall is solid. There is only one opening into the cavity, the mouth. Other animals, like the earthworm, have a

tubular digestive system, with a mouth at one end and an anus at the other. Around this tube there is a fluid-filled space, the *cœlom* or body-cavity, which intervenes between it and the solid body wall. The earthworm is again a good illustration of this point.

6. *Appendages.*—Many animals possess appendages to the body proper in the form of paddle-like swimming organs, fins, jointed legs, etc.

7. *The Type of Skeleton* (Fig. 17).—Animals may have hard structures on the outside (*exoskeleton*) or inside (*endoskeleton*) of the body. In the vertebrates and their relatives the skeleton is typically of the latter type and its central axis always originates as a rod-like organ, the *notochord*, or *chorda*, which extends longitudinally through the body. In the vertebrates proper the chorda is replaced during early development by bony vertebræ which form the spinal column, or "backbone."

Using such criteria, it is possible to divide the animal kingdom into fifteen great groups, or *phyla*, which may be identified by means of the following "key":

KEY TO PHYLA OF ANIMALS*

1 (2) Body composed of one cell or a colony of similar cells; mostly microscopic.....Phylum I, PROTOZOA.
2 (1) Body composed of many cells arranged in tissues.....3
3 (24) Body non-metameric.....4
4 (11) Radially symmetrical. Have proximal (attached) and distal (free) ends, or have oral (mouth) and aboral surfaces, but have no head or tail. Parts of body radiate around a chief axis...5
5 (6) Body filled with many minute pores; no definite mouth. Sponges.....Phylum II, PORIFERA.
6 (5) Body not filled with pores; a mouth present.....7
7 (8) Body with eight rows of comb-like plates arranged radially. Phylum IV, CTENOPHORA.
8 (7) Body without eight rows of radially arranged paddle-plates..9
9 (10) Body sac-like, often with tentacles. Polyps, medusæ, jelly-fishes, corals, sea-pens....Phylum III, CŒLENTERATA.

* In using the key there are always *two* alternatives. The first number is to be compared elsewhere with the one in parenthesis after it.

10 (9) Skin usually spiny; body a tube within a tube; marine. Starfishes, sea-urchins, brittle stars, sea-cucumbers, stone-lilies. Phylum IX, ECHINODERMATA.

11 (4) Bilaterally symmetrical. Have anterior (front), posterior (hind), right and left, dorsal (back), and ventral (belly) regions....12

12 (15) Body soft, flat, worm-like....13

13 (14) One opening into digestive cavity; or no digestive cavity. Phylum V, PLATYHELMIA.

14 (13) With mouth and anus....Phylum VI, NEMERTINA.

15 (12) Body not flat and leaf-like....16

16 (17) Body cylindrical, worm-like; without anterior ciliated* lobes. Phylum VII, NEMATOIDEA.

17 (16) Body not as described under 16....18

18 (21) Small, often microscopic, aquatic animals; solitary or growing in branching plant-like colonies....19

19 (20) Microscopic worm-like animals with two ciliated* lobes at the anterior end and a chewing stomach within the body. Phylum VIII, ROTIFERA.

20 (19) Attached colonial animals which have a superficial radial symmetry....Phylum X, BRYOZOA.

21 (18) Larger animals; often possessing a hard shell which may cover the body....22

22 (23) Stalked attached marine animals with a shell composed of two (dorsal and ventral) valves. Lamp shells. Phylum IX, BRACHIOPODA.

23 (22) Soft-bodied animals, usually with a shell and a ventral muscular "foot"....Phylum XIV, MOLLUSCA.

24 (3) Body metameric and bilaterally symmetrical....25

25 (28) No jointed appendages, body worm-like (snakes belong under 30)....26

26 (27) Microscopic animals, with ciliated lobes at the anterior end of the body and a chewing stomach within. Phylum VIII, ROTIFERA.

27 (26) No ciliated lobes at anterior end; body with minute bristles along the sides or with an adhesive sucker at one or both ends. Phylum XII, ANNELIDA.

28 (25) Jointed appendages (except in limbless amphibians, snakes, and limbless lizards)....29

29 (30) External skeleton (turtles, which have both exo- and endoskeletons, belong under 30); no chorda. Phylum XIII, ARTHROPODA.

30 (29) Endoskeleton; chorda or backbone present. Phylum XV, CHORDATA.

* Cilia are microscopic hair-like processes which usually wave actively.

CHIEF PHYLA OF THE ANIMAL KINGDOM

Subkingdom Protozoa

1. **Protozoa** (*protos*, first; *zoon*, animal).—Animals made up of a single cell. The cells may grow together in colonies but never show any division of labor as tissues. Examples: Amœba, Euglena, Paramœcium, malarial parasite, Volvox. 8500 species.

Subkingdom Metazoa

2. **Porifera** (*porus*, pore; *fero*, carry).—The body radial or without definite symmetry, filled with numerous small inhalent pores, and with one or more large apertures where water is expelled. Cellular tissues and germ, or reproductive, cells are well developed, but not laid down in fundamental germ layers. A skeleton made up of lime, silica, or horny material is often present throughout the body. Peculiar cells bearing collars line some of the canals of the interior. Tissues are well developed but there are no organs. This phylum includes the sponges, which are attached and usually grow up from the bottom somewhat like water plants. 2500 species.

3. **Cœlenterata** (*koilos*, hollow; *enteron*, intestine).—The body radially symmetrical, usually with four or six antimeres; diploblastic (with two primary cell-layers); with a single gastro-vascular cavity and no anus. The body-wall is provided with peculiar stinging structures—the nematocysts. Examples: Hydra, jellyfishes, zoophytes, polyps, and corals. 4400 species.

4. **Ctenophora** (*ktenos*, a comb; *phoreo*, I bear).—Animals possessing radial combined with bilateral symmetry; with eight radially arranged rows of paddle plates; triploblastic (with three primary cell layers); anus usually present. Sea Walnuts or Comb-jellies. 100 species.

5. **Platyhelmia** (*platys*, flat; *helminthos*, a worm).—Flat, bilaterally symmetrical, triploblastic animals; with a single gastro-vascular cavity having no anus, or without a diges-

tive system; a very small cœlom present. A well-developed system of excretory tubes present. Flatworms: planarians, flukes, tapeworms. 5000 species.

6. **Nemertina.**—Flattened worms which resemble the Platyhelmia in general appearance, but are more specialized. An anus is present at the posterior end of the body. The nemerteans. 280 species.

7. **Nematoidea.** (*Nematos,* a thread).—Cylindrical or thread-like, bilaterally symmetrical, non-metameric, triploblastic worms. A mouth and anus are present and the body is of the "tube-within-a-tube type." The body cavity is, however, unlined and hence not a true cœlom. Round-worms: Trichina, hook-worm, vinegar-"eels," etc. 1500 species.

8. **Rotifera** (*rota,* a wheel; *fero,* I carry).—Microscopic, bilaterally symmetrical, metameric, triploblastic animals; with a cœlom; two ciliated lobes, which often look like rotating wheels, at the anterior end. The digestive system is tubular, with a mouth, anus, and several distinct regions. There are chewing teeth in the stomach. A pair of water canals are present which serve for excretion. The wheel-animalcules. 500 species.

9. **Brachiopoda** (*brachion,* the arm; *pous,* a foot).—Marine, bilaterally symmetrical, triploblastic animals; which possess a bivalve shell (valves dorsal and ventral) and are usually attached by a stalk. A peculiar horseshoe-shaped structure in front of the mouth gives the name to this phylum. The body is very small in proportion to the size of the shell. The lamp shells, which are mostly extinct, are examples. 500 living species.

10. **Bryozoa** (*bruon,* moss; *zoon,* animals).—Small, usually colonial animals, which are mostly marine. The colony usually has a branching plant-like form. At the tips of the branches are the individual animals which have a superficial radial symmetry. A number of tentacles surround the mouth and a U-shaped digestive tube leads to the anus. 1200 species.

11. **Echinodermata** (*echinos*, hedgehog; *derma*, skin).—Radially symmetrical animals, usually with five antimeres. A large cœlom is present, and there is a peculiar system of tubes called the water-vascular system. An anus may be lacking and is often non-functional when present. There is usually a calcareous, spiny skeleton. Starfishes, brittle-stars, sea-cucumbers, sea-urchins, stone-lilies. 4000 species.

12. **Annelida** (*annulus*, ring).—Metameric, bilaterally symmetrical, triploblastic, soft-bodied worms. Body clearly a tube within a tube—*i.e.*, cœlom very well developed; paired excretory organs (*nephridia*) in each segment of the body; no jointed appendages. Earthworm, marine worms, leeches. 4000 species.

13. **Arthropoda** (*arthron*, joint; *pous*, foot).—Metameric, bilaterally symmetrical animals; with a chitinous exoskeleton and jointed appendages; cœlom poorly developed. Crustaceans, insects, spiders, centipedes, scorpions, ticks. 400,000 species.

14. **Mollusca** (*mollis*, soft).—Non-metameric, bilaterally symmetrical, triploblastic animals; in which there is a well-developed digestive system with mouth and anus, a small cœlom, and usually a calcareous exoskeleton in the form of a shell. Clams, mussels, snails, slugs, devil-fishes, octopi. 60,000 species.

15. **Chordata** (*chorda*, cord or string).—Triploblastic, metameric, bilaterally symmetrical animals; with well-developed cœlom and an endoskeleton—the chorda or other supporting structures. Paired appendages are usually present, and these are often jointed. Fishes, newts, frogs, reptiles, birds, mammals. 36,000 species.

The relationships of the phyla are shown in Fig. 18.

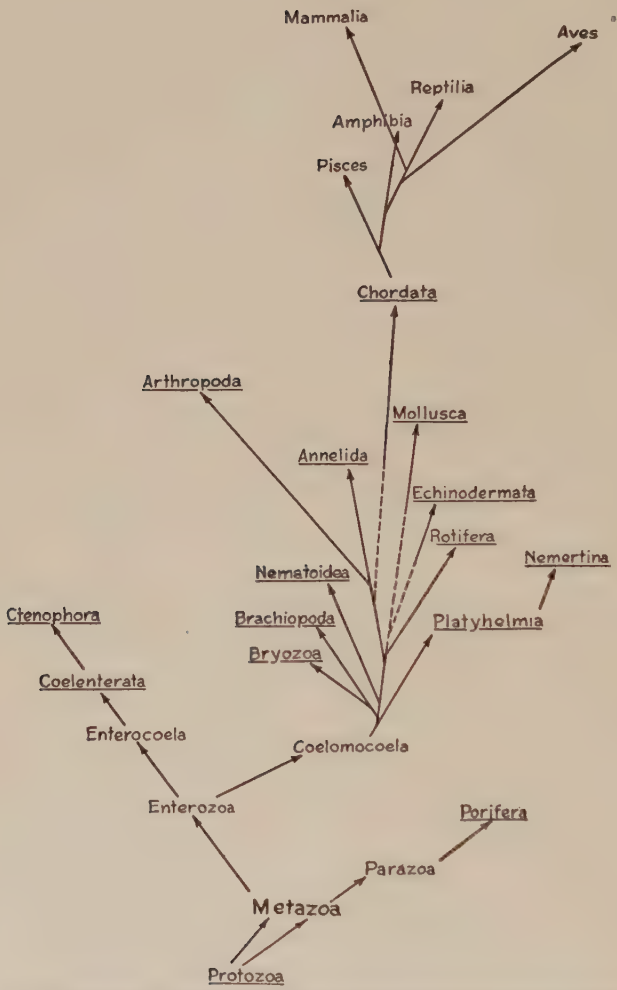


FIG. 18.—Showing the probable relationships of the phyla of animals.

CHAPTER III

LIFE AND LIVING THINGS

"Just as the search for the philosopher's stone that was to transmute the baser metals into gold, led through alchemy to the foundations of modern chemistry, and to a richer reward than the long-sought stone, and as the vain pursuit of the elusive *elixir vitæ*, that was to renew youth and vigour and give unending life at the prime, merged into the beginnings of scientific medicine; so the inquiry into spontaneous generation, or the origin of life, opened up the whole of our modern knowledge of the causation of disease through the discoveries of Pasteur, and onward beyond that laid the broad foundations for the wonderful developments of modern surgery which arose from the noble lifework of Lister. Millions of lives have been saved, and untold misery and suffering averted, by practical discoveries which arose from apparently purely philosophical enquiries dealing with theories which might have been dismissed as chimerical." Moore.

What is life? No one knows! Definitions have been formulated which will enable us to separate living from non-living things, but when it comes to knowing *why* a living thing is alive we have little that is satisfying from a scientific point of view. Things are alive because they have life. It may seem idle to pursue a discussion which in the end will lead us back to where we started, but we may, nevertheless, look with profit into the facts and theories which relate to living things. Because we cannot answer a question is no reason why we should not try. Maybe, sometime, by trying, the answer will be found.

ORIGIN OF LIFE

In the past many curious notions have been held in regard to the origin of individual animals. It was at one time commonly believed that small aquatic animals generated from mud, and that decaying meat was transformed into

maggots. Van Helmont, a deservedly eminent scientist of the sixteenth century, was a firm believer in such *spontaneous generation,* and soberly stated that mice could be produced by placing some dirty linen in a receptacle, together with a few grains of wheat or a piece of cheese. Such crude ideas show the low level of the scientific thought of the time. The belief that organisms commonly originated from inorganic materials or decaying substances was prevalent.

The first critical experiments which helped to do away with the belief in spontaneous generation were performed by an Italian poet and physician, Franchesca Redi. He demonstrated clearly that fly maggots were not engendered spontaneously in spoiled meat, but developed from eggs deposited by flies. He set three jars on his window sill—one was uncovered; one covered with gauze so that the air might enter freely but no flies could come in; the other was corked tightly. Though the meat in all the bottles spoiled, maggots appeared only in the uncovered jar. The flies were seen to lay their eggs, and the hatching of maggots was observed. Redi's epoch-making discovery seems very simple to us, but it aroused a storm of discussion and dispute in his time.

It would perhaps be expected that the invention of the microscope would at once have furnished the means to disprove spontaneous generation, but it had the opposite effect. This instrument opened up a new world of minute "animalculæ," and with these the advocates of spontaneous generation made their last stand. It was found that if dry hay was put in water, cooked to destroy any living germs which might be present, and allowed to stand for a day or two, that the "infusion" was filled with myriads of "animalcules." This experiment was believed to prove that the organisms were generated from the disintegrating hay. Later, however, it was urged that the animalcules might enter the infusion from the air. Experiments were tried in which infusions were sealed up in tubes, both before

and after boiling. Spallanzani, in the middle of the eighteenth century, wrote: "I used hermetically sealed vessels. I kept them for an hour in boiling water, and after opening and examining their contents after a reasonable interval, I found not the slightest trace of animalcule, though I examined with the microscope the infusions from nineteen different vessels." The question was still discussed, however, and even as late as 1858 a French scientist read a paper before the National Academy in which he announced that animalculæ had been raised in boiled infusions exposed only to "artificial air," or oxygen. He maintained that the organisms could not have arrived as air-borne particles.

This paper excited the interest of Pasteur and led to the work which finally laid the idea of spontaneous generation to rest. "He showed that sterilized cultures always became infected when exposed to air; that properly filtered or sterilized air never caused infection; that Alpine air almost free from germs scarcely ever produced a growth of organisms; that city air nearly always produced contamination; and that, in absence of added germs from without, culture media remained sterile for years. The sources of error in the work of his opponents were elucidated, and their contrary results explained on such grounds." Tyndall also furnished evidence of a physical nature which corroborated the discoveries of Pasteur. He was trying to get a beam of light which was perfectly free from dust particles and made an apparatus in which the light was passed through windows in an air-tight box. When the box was absolutely dust-free there was no fermentation within it, thus demonstrating that the origin of bacteria and similar organisms was due to air-borne particles.

At the present time, the only generalization we can make concerning the origin of living things is, "all life comes from life." Every living organism originates from a preëxisting individual of its own sort. This conclusion is unsatisfying,

from a scientific point of view, and, of course, does not explain the origin of life.

PHYSICAL BASIS OF LIFE

If we cannot explain the origin of life we may at least look into the nature of living matter. The name, *protoplasm*, has been given to the complex mixture of chemical compounds which makes up the living substance. It is a transparent semi-fluid material, somewhat like the white of an egg. At one time there was considerable dispute in regard to the structure of protoplasm. One school maintained that there were granules which were all-important; others, that little fibers were the living elements; a third group that little bubbles were the necessary feature. Modern investigation has shown, however, that none of these things are of prime importance. The same bit of protoplasm may at different times be granular, or reticular, or alveolar. It is more or less clear and jelly-like; it shows spontaneous internal movements; it is alive—these are the only constant features to be seen even through the best microscopes.

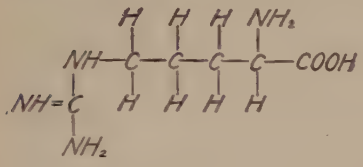
Protoplasm is somewhat variable in its composition because it is unstable chemically, and is continually changing. Nevertheless, it shows a general similarity of structure and elemental composition in all plants and animals. It is made up of twelve of the eighty-odd known chemical elements. These are:

Carbon, oxygen, hydrogen, nitrogen, sulphur—99 per cent.

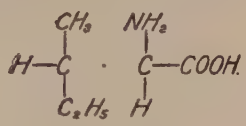
Chlorine, phosphorus, potassium, sodium, magnesium, calcium, iron—1 per cent.

Protoplasm shows some chemical peculiarities which are noteworthy. (1) The element carbon has remarkable ability to form extremely complex systems of combinations with other elements and its compounds are most important (Fig. 19). (2) Protoplasm is very labile, or unstable. Living substance may readily incorporate a little more water (or other compound) or lose a little as the necessity

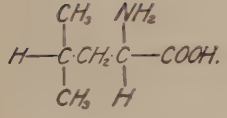
arises. This ability to change continually yet be essentially the same is perhaps the most striking quality of protoplasm. (3) The most important and characteristic chemical compounds in protoplasm are colloidal—*i.e.*, they consist of enormous molecules, which mix readily with water but never completely dissolve, as many crystalline substances do. The most important colloidal substances are the proteins. These contain carbon, oxygen, hydrogen, and nitrogen and possess various unique properties. They are made up of enormous molecules which may be readily



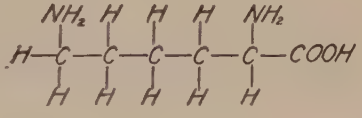
Arginine



Isoleucine



Leucine



Lysine

FIG. 19.—Some of the chemical compounds formed when protoplasm breaks down. In these diagrams the significance of the letters is as follows: *c*, carbon; *h*, hydrogen; *n*, nitrogen; *o*, oxygen.

modified by adding or eliminating whole groups of atoms. If we compare an atom to a soldier, we may liken a protein molecule to an army corps in which a regiment of infantry, or a hospital unit, or some other part is continually being transferred from one position to another. One like the other has a certain recognizable unity—yet the internal arrangements are never continuously the same.

The chemical compounds which make up protoplasm are not all organic. Inorganic compounds are present in considerable quantity. Water is an universal constituent of protoplasm and there are always mineral salts, such as the

phosphates, chlorides, and carbonates of calcium, potassium, magnesium, and iron. Some jellyfishes are more than 99 per cent. water.

Organic compounds were formerly believed to come only from living things—but now the chemist may make thousands of them in his laboratory, and many are of vast commercial importance. The chief classes of organic compounds are proteins, carbohydrates, and fats. *Proteins* differ from the others in that they contain nitrogen in addition to carbon, oxygen, and hydrogen. They constitute the greater, and most essential, part of the protoplasm. Lean meat and white of egg are examples of substances which are largely made up of proteins. *Carbohydrates*, of which sugars and starches are examples, have their oxygen and hydrogen in the same proportions (H_2O) in which they occur in water. *Fats*, or hydrocarbons, contain the same elements as carbohydrates but in different proportions, so that there is a smaller percentage of oxygen.

It is possible for the chemist to analyze protoplasm to some extent and to learn the exact formulæ for some of the chemical compounds present, but its protein molecules are so large that their exact composition and arrnagement is still a matter of uncertainty in most cases. Here again, then, we are met with an unsatisfactory termination in our search for the fundaments of life. When we try to analyze living substance, it dies, and we have left a number of complex compounds (Fig. 19) which, though perhaps simpler than those present during life, are still of such complicated structure that they are imperfectly known.

MECHANISM AND VITALISM

Notwithstanding our comparative ignorance concerning the phenomena of life men have not been backward in putting forth theories to explain the operation of living things. There has been long and bitter controversy between the mechanists, who maintain that living matter is

not essentially different from non-living, and the vitalists, who hold that living things possess a vital principle which makes them different from non-living.

The mechanist believes it is possible that no living machine is beyond experimental analysis. He expects as his knowledge grows broader to know more and more about the mechanism of life, and even hopes, sometime, to be able to make a living organism himself. From a scientific point of view it is certainly not satisfying to believe that all things were created as they are; that living things are alive because they are alive, and that it is of no avail to try to discover how they came to live and are living. It would be equally unscientific to say that living things were not created. There is no proof either way. Yet the mechanist has much on his side.

The first big victory for the mechanists was the discovery that organic compounds can be made synthetically. When Woehler in 1828 made urea in his laboratory, he opened up a new field which has been very fruitful. It had been believed that such substances could only be elaborated within the bodies of living organisms. For example, Liebig, who was a man of good standing scientifically, manufactured a beef extract which he claimed was nourishing because it possessed something "vital." One of his opponents tested the extract, to see if such was the case. He took a litter of kittens from their mother. Half of them were fed nothing and the others received beef extract. The starved lot lived longer than the others, showing that the extract had little food value, but was stimulating. When it became known that not only urea but many other organic compounds could be made synthetically, people began to doubt the "vital principle."

There is no question that every organism is a machine. It is composed of matter which may be separated into well-known chemical elements and compounds. It consists of levers, pulleys, and other things which work according to the laws of mechanics. Many complicated activities

which were once believed to show the presence of some vital quality are now understood and may be controlled at the will of the experimenter. A turtle's heart may be taken from its body and placed in saline solution where it will continue to beat rhythmically for two or three days. Furthermore, its rate of beat may be regulated. If a certain mineral salt is added to the solution in which it lies, it beats faster; if another is added, it slows down and even ceases to pulsate, but will begin again if the solution is restored to its original condition.

Another stroke for mechanism came with the knowledge of the control of "vital" activities through enzymes and hormones. For example, there are in every man a pair of glands, the thyroids, on either side of the neck which are very necessary to "vital" activity. They give off a substance, thyroidin, which enters the blood stream and is constantly necessary for the proper nourishment of the body. Goitre is the name given to a diseased, swollen condition which may interfere with the proper functioning of the thyroids. It was in trying to find a cure for this trouble that some interesting facts were discovered. It was found that, if diseased glands were removed, the body would waste away and the patient finally died. But if, after taking out the glands, thyroidin from a healthy sheep was injected hypodermically, there was no disturbance. Furthermore the same result could be obtained by grafting a fresh thyroid beneath the skin. Thyroidin is, then, necessary in the body of man, but it makes little difference how it is supplied. The machine needs a certain amount of the substance to run properly but the thyroid gland is not necessary any more than an oil cup is necessary for an engine if oil is supplied in some other way. Many other substances control or facilitate various activities which were once believed to be dominated by "vital spirits."

Arguments might be multiplied which tend to show that living animals are machines, but let us look at the other

side. The vitalist has only one argument—no mechanist has ever made a living thing or brought a dead thing to life. He believes that even though we could understand living mechanism and its workings completely, we would still not be able to produce life without some preëxisting life to start it off. Vitalism involves more than this, there is belief in a fundamental difference between the living and non-living. There must be something "vital" present without which an organism will cease to be alive. Some vitalists call this vital principle the soul. There are those who believe that all living things have souls, and others who feel that such a quality is confined to a few of the higher animals or to man alone.

Until we learn more, there can be no final decision between vitalism and mechanism. The radical mechanist can continue to say that we have no proof of anything vital, or divine, and can assert, if he chooses, that "vitality" is simply a name for a lot of things we do not yet understand. The vitalist can still hold that the mechanist has never proved his point—living things are different from non-living and, through scientific reasoning, we cannot show why. A scientific attitude compels us to accept nothing until it is proved. Very little is yet proved. If we knew more we probably would not argue so much. Professor Wilson in a recent address said, "And so, if you ask whether I look to a day when we shall know the whole truth in regard to organic mechanism and organic evolution, I answer: No! but let us go forward."

CHARACTERISTICS OF LIVING THINGS

It is difficult to formulate absolute differences which will always separate living from non-living objects. It is possible, however, with some confidence to set forth the following six qualities which will serve to characterize living organisms.

1. *Determinate Size and Structure.*—All animals and plants vary to a considerable extent, in fact, it is often said

that no two are alike, yet each species when adult has a certain average size and form which enables one to recognize it. A cat is never as large as a cow; a birch tree is never found with the bark or leaves of an oak. Living things cling to such specificities generation after generation.

2. *Precise Elementary Composition.*—Living matter, though highly variable, is made up of only twelve of the eighty odd chemical elements available in nature. These

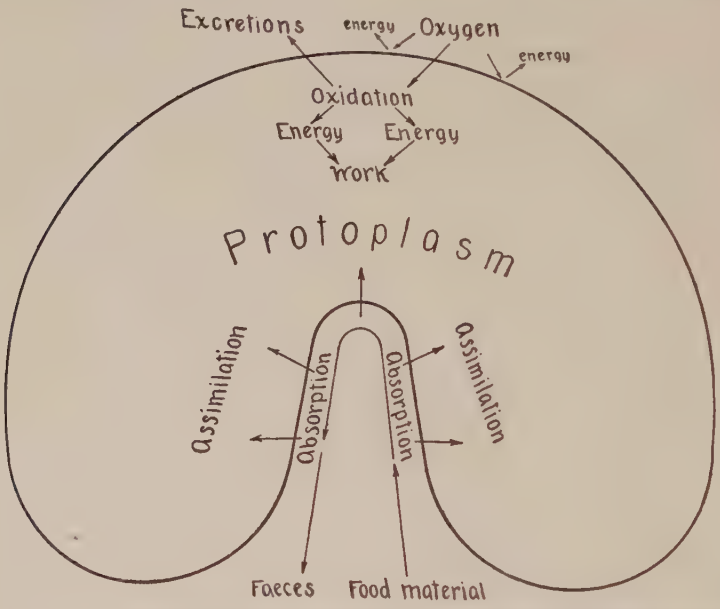


Fig. 20.—A scheme showing metabolism, or the chemical changes continually going on in protoplasm. No living thing can stand still. It must change continually.

occur in definite proportions and form only certain kinds of compounds.

3. *Definite Organization.*—Living organisms are composed of a variety of unlike parts which are generally incapable of independent existence. The smallest unit of organic structure is a cell and in large animals there may be billions. The parts of an animal will not exist separately—you cannot remove a kidney or a stomach and have it remain

active because the functioning of such an organ depends upon its surroundings.

4. *Metabolism* is the name for the complex of chemical changes continually taking place in living things. Nothing which is alive can stand still, *it must change.* Some changes are constructive (*anabolism*), some are destructive (*catabolism*). In general there is an orderly sequence in the transformation of substance. Material is *appropriated*, *digested* (changed chemically and dissolved), and *assimilated* (or converted into living substance). If any of the material is not fit for food, it is rejected as *fæces.* In order to furnish energy to transform materials and build substance, oxidation takes place, and this makes

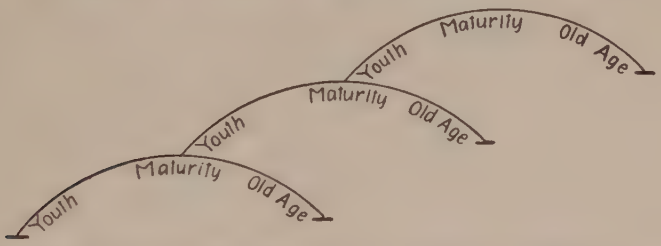


FIG. 21.—Scheme showing the life cycle through which every living thing must pass.

respiration necessary to supply the oxygen. After living substance has been broken down a residue is left which passes out as an *excretion* (Fig. 20).

In addition to this continual daily rhythm there is another series of periodic changes which is characteristic of living things. This is called the *Life Cycle*, during which an organism passes through the stages of youth, maturity, and old age. A young animal has great vitality—it grows rapidly and has an abundance of energy. A mature animal is at its best—the machine is complete and perfect. Usually at this stage reproduction takes place and a new cycle is started by setting free a young animal. In old age the machine wears out and death finally puts an end

to the cycle. Every animal must run in the race of life; and the goal for all is the same—death.*

5. *Reproduction.*—All living things have the power to perpetuate their race. Some animals split themselves in two, or break up into fragments, and each of the pieces grows into a complete new individual. Such multiplication increases the number of organisms easily and quickly. At times, however, most animals have some means of proper *reproduction* during which there is fusion of products from two individuals to form a third—and this new individual starts out with all the vigor of youth, though its parents may have been at the other end of the cycle.

6. *Adaptability or Reactiveness.*—All organisms are able to adjust themselves to their surroundings and this ability to meet changing conditions is perhaps the most characteristic attribute of living things. Garden spiders always spin webs of the same type, yet one may fill a square, and another a triangular space. Individuality is thus retained but adapted to varying conditions. The success of any man depends upon his adaptability—how well he can meet the difficulties and changing conditions of life.

* Except in some Protozoa, which may escape death from old age by becoming young again (see Chapter XII).

CHAPTER IV

CELLS

Protoplasm, or living substance, occurs only in the form of cells. These "units of life" are in a certain sense like the bricks from which men make houses. Bricks are of various colors and shapes, they may be built into houses or they may exist as separate chunks of burnt clay, yet anyone recognizes a brick when he sees it. Brick houses may have doors, various arrangements of windows, porches, and other embellishments without changing the essential character of the bricks which furnish the bulk of their mass.

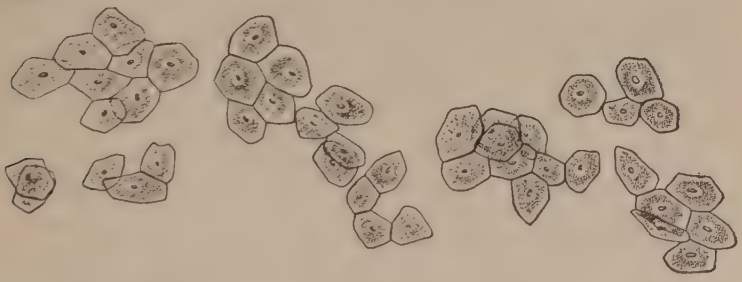


FIG. 22.—Cells scraped from the inside of a man's cheek.

Living substance always occurs in the form of cells. Many of these "units of life" are independent (Protozoa); they are able to reproduce themselves, carry on metabolism, and maintain all the other activities characteristic of living things, as described in Chapter III. Other cells live as small units in the midst of great living machines and are incapable of independent existence. A recent estimate places the number of the nerve cells in the cortex of the human brain at 9,280,000,000, and yet these would together occupy only about one cubic inch of space. The

greater part of the brain substance is made up of nerve fibers, other types of cells, and their products. The whole body contains a vast number of such units. Though cells are highly variable in size and shape, they have certain structures which are familiar to everyone who has looked through a microscope at any thing living.

If you scrape a little of the membrane from the inside of your cheek and place it under a microscope, the fragments will appear like Fig. 22. The individual cells are flattened and irregularly hexagonal in form. Each one has, at the center, a body of somewhat denser material, the *nucleus*.

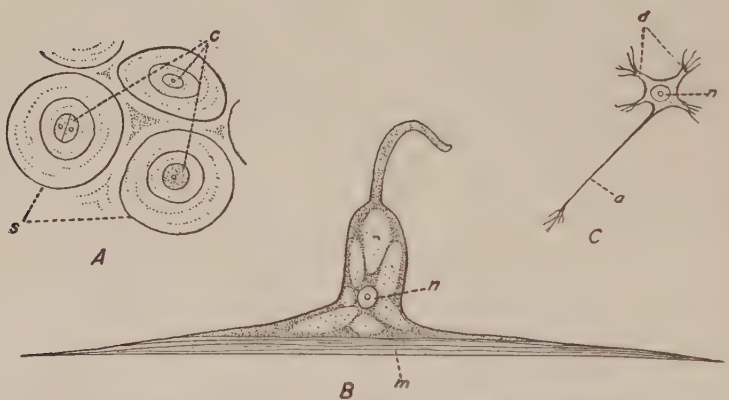


Fig. 23.—Examples of cells. *A*, cartilage; *c*, cells; *s*, the substance between the cells. *B*, a muscle cell from a round-worm; *m*, muscular or contractile portion; *n*, nucleus. *C*, nerve cell; *a*, axis cylinder process; *d*, dendrites, or root-like projections; *n*, nucleus.

The rest of the cell substance, *i.e.*, the outside part which surrounds the nucleus, is the *cytoplasm*. Other parts of the body will show cells somewhat like those from the cheek. All have a nucleus and cytoplasm, but there may be great variation in both. Some cells have walls of secreted material around them which forms "cell-walls," others have the cytoplasm drawn out into long projections, or vary in other ways. Fig. 23 shows a few examples of cells.

Fig. 24 gives a general scheme of a typical cell with all

the structures commonly present. The cytoplasm is usually made up of fibers, granules, and fluid *plasma*. Other bodies such as crystals, oil globules, and water vacuoles, may be present. Such "extra" bodies are called *plastids*, *metaplasm*, etc. The nucleus is covered by a membrane and has, besides some fluid plasma, a network of *linin fibers* to which are attached irregular masses of *chromatin*. Just outside the nucleus is the *centrosphere* which contains two *centrosomes*.

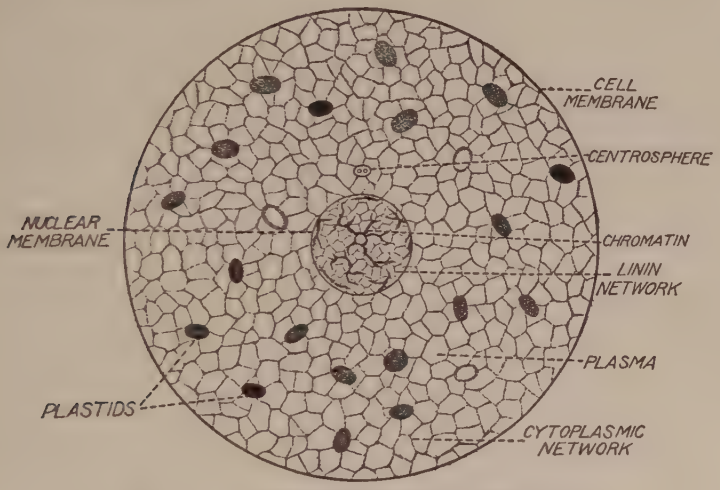


FIG. 24.—A typical cell showing all the parts.

There is a division of labor among the structures mentioned. The plasma membrane on the outside of a cell is semi-permeable, allowing certain substances to pass into or out of the cytoplasm but not admitting others. The cytoplasm does the work which is the particular task of each cell. In a muscle cell it is specialized for contraction; in a nerve cell it carries the nervous impulses. The cytoplasm may also store food or even waste products. The general function of the nucleus appears to be the control of synthetic metabolism. A cell without a nucleus may work until its reserve energy is exhausted, but it can never build up any new material. The chromatin in the nucleus

appears to be the chief bearer of hereditary qualities from one cell to another. How the transfer of hereditary characters is believed to take place will be explained later (Chapter XXX). The centrosomes are apparently inactive except when the cell divides. They then commonly form dynamic centers which are concerned with the separation of the chromatin material.

Cells rarely exceed the size which is usual for their particular kind. The largest in animals, such as some nerve cells, are two or three feet long. Most cells, however, are much smaller and usually cannot be seen with the naked eye. The smallest bacteria are less then one twenty-five thousandth of an inch in diameter. When a cell has grown so that it threatens to exceed the maximum set for its kind by natural causes, it divides. Cell-division is important in several ways. It allows cells to grow without becoming too large, and it increases the number of cells. In many celled animals, growth is closely bound up with cell-division and cell-differentiation. Cell-division is, therefore, a very important biological phenomenon. There are two types: mitotic and amitotic.

MITOSIS OR INDIRECT CELL-DIVISION

Mitotic cell-division is a rather complicated process which results in the accurate division of the chromatin of the nucleus and a somewhat less precise separation of the other parts of the cell. The changes which take place are grouped under five stages (shown in Fig. 25) which may be described as follows:

1. *Resting Cell.*—A resting cell ready for division does not differ from any other cell, except that the nucleus is large in proportion to the cytoplasm. The centrosomes lie at one side of the nucleus and the chromatin is scattered irregularly through the linin network.

2. *Prophase.*—The centrosomes move apart and take positions on opposite sides of the nucleus. Long strands

stretch out from them in all directions and in the zone between the centrosomes these form a framework, the *spindle*. The chromatin has meantime formed a long thread, the *spireme*, and this later breaks up into a number of compact rods of chromatin material, the *chromosomes*. The nuclear membrane now breaks down and the chromosomes arrange themselves around the center of the spindle halfway between the centrosomes.

3. *Metaphase.*—Each chromosome splits into two equal parts.

FIG. 25.—Mitosis, or indirect cell division. The chromatin is very accurately divided because it is the bearer of hereditary qualities.

4. *Anaphase.*—The new chromosomes formed by splitting in the last stage migrate toward the nearest centrosome. Thus half go toward each pole of the cell.

5. *Telophase.*—The chromosomes break up into scattered bits of chromatin and a nuclear membrane is formed about each of the two groups. The centrosomes divide and the new pairs come to rest beside their respective nuclei. A separation takes place in the cytoplasm between the two nuclei, thus completing mitosis and forming two cells.

It seems strange that the division of a minute bit of living matter should involve such a complicated mechanism

as has been described. The purpose of mitosis is apparently to secure the accurate division of the chromosomes—so that each daughter cell may receive exactly the same amount of chromatin. The chromosomes are believed to be the chief bearers of hereditary qualities and have been known as the "vehicles of inheritance." This perhaps explains why such care is taken to insure accurate division.

There is a characteristic number of chromosomes for each plant or animal and when one of its cells divides the same number is always reformed from the scattered chromatin of the nucleus. Thus the number in several animals is as follows:

Ascaris, a nematode	2 or 4	Rana, a frog; and man	24
Aphis, a plant louse	8	Lumbricus, an earthworm	32
Gryllotalpa, a cricket	12	Crepidula, a snail	60
Rat	16	Artemia, a brine-shrimp	168

It is known that species in the same genus show constant differences in the number of chromosomes. Each shows its characteristic number generation after generation. Sometimes there is an odd chromosome. This peculiarity is particularly characteristic of the sex cells of certain animals. In such cases, the minute male sex cell, or spermatozoon, may carry the odd chromosome and is believed to produce a female when it "fertilizes" an egg; one which has none will give rise to a male. The odd chromosome, therefore, perhaps serves to determine sex.

AMITOSIS OR DIRECT CELL-DIVISION

When the cell divides without mitosis the process is very simple. The nucleus elongates, becomes constricted in the middle like a dumbbell, and finally is pinched in two (Fig. 26). The two daughter nuclei may differ greatly in size and in the amount of chromatin they contain. Amitosis often takes place in old, weak, or degenerate cells and may be looked upon, at least in some cases, as a sign of a general wearing out of the cell mechanism. Some students of cell physiology dispute this interpretation, however.

Amitotic cell-division is often a means of increasing the nuclear surface in a cell. In many active cells the nucleus becomes very much branched, and it is only a step beyond this to have it break up into pieces. It will be remembered that the nucleus controls synthetic metabolism in the cytoplasm around it. The cell can build up faster with the increased surface brought about by division, just as man can freeze ice cream faster with small pieces of ice than he can with large chunks.

Cell-division does not take long—in some cases from ten minutes to half an hour. Many cells in your body have divided mitotically since you started to read this chapter. As to differences between the two types—mitosis is pri-

FIG. 26.—Amitosis, or direct cell division. The nucleus elongates and pinches in two. A membrane is formed between the two new nuclei, thus making two cells. Amitosis is a quick method of increasing nuclear surface.

marily for the exact division of the chromatin; amitosis is chiefly for increasing the amount of nuclear surface in proportion to the cytoplasm.

THE CELL THEORY

The modern "cell theory" asserts that cells are the units which build every living organism. No plant or animal exists which does not have the protoplasm divided upon into cells. Though this view is generally accepted by the scientific world, it is less than a hundred years since it was pronounced.

In 1665 an Englishman named Hooke, when making a careful examination of a piece of bark, discovered that it was made up of little compartments arranged in regular

rows (Fig. 12). Likening these to the rooms in monasteries Hooke gave them the name, cells.

Later workers found cells in various plants and animals, but they were merely looked upon as interesting features without particular importance. It was in 1833 that another Englishman, Brown, discovered the nucleus, which he described in certain plant cells. Not until 1838–1839 was the Schleiden-Schwann Cell Theory brought before the scientific world by the two Germans whose name it bears. In 1838 Schleiden asserted that all plants were made up of cells; and in the next year, Schwann published a great work which convinced everyone that not only plants but animals as well were made up wholly of cells.

No generalization, unless it be Darwin's "Origin of Species," has so stimulated biological investigation as the cell theory. A new field was opened up which led to the discovery of the method of the fertilization of eggs and other fundamental matters which had not been previously understood.

It is unfortunate that the name "cell" was given to protoplasmic units. One thinks of a cell as a box or hollow thing. A biological cell, however, is cytoplasm and nucleus. The cell-wall, which originally gave the name, is not a constant feature, and in animal cells is more often absent than present.

CHAPTER V

PHYLUM ARTHROPODA, CLASS CRUSTACEA, LAW OF BIOGENESIS

The animals belonging to the phylum Arthropoda are readily distinguished from all others by the presence of an exoskeleton and by the uniform occurrence of paired, jointed appendages arranged metamerically. This is an important phylum numerically for it contains more species than all the rest of the animal kingdom—400,000 or more. It includes the crayfishes, crabs, centipedes, insects, spiders, ticks, scorpions, etc.

In order to understand the general structure and relationships of the arthropods, examine Fig. 27. This shows the structure of an hypothetical ancestor which may be supposed to have given rise to all the existing groups of arthropods. This imaginary animal was worm-like, metameric, and had a tubular digestive system with a mouth at one end and an anus at the other. There was a hard exoskeleton, covering every segment of the body, and metameric appendages. The appendages were rather broad and flat; each consisted of a jointed basal piece and two distal portions—hence, was a biramous appendage.

Anterior and posterior ends were well differentiated. Several segments at the anterior end had grown together to form a head which bore a pair of antennæ, a pair of eyes, and a pair of biting jaws or mandibles. A pair or two of appendages, the maxillæ, which were added to the head when the metameres just behind fused with it, had come to serve with the mandibles as "mouth parts" for manipulating the food. At the posterior end of the body the appendages had perhaps become specialized for purposes of reproduction.

Inside the body there was a tubular digestive system extending from mouth to anus. This began as a gullet or esophagus, was enlarged a little behind the head to form a stomach, and continued through the rest of the body as a straight intestine. Above the alimentary canal there was a long tubular heart which received blood through paired openings in each metamere and pumped it forward. The nervous system consisted of a "brain" (the supraesophageal ganglion), dorsal to the esophagus, and a chain of metameric masses of nerve cells, or ganglia, on the ventral side of the alimentary canal. There were nerves from the ventral chain of ganglia to each of the appendages and to the internal organs; branches from the brain supplied the optic (or eye) ganglion, the antennæ, and some of the mouth parts. There was a pair of kidneys in each metamere which opened to the outside through pores in the exoskeleton. Near the posterior end of the body were a pair of tubes (the gonads, or sex glands), which shed egg- or sperm-cells through the anus.

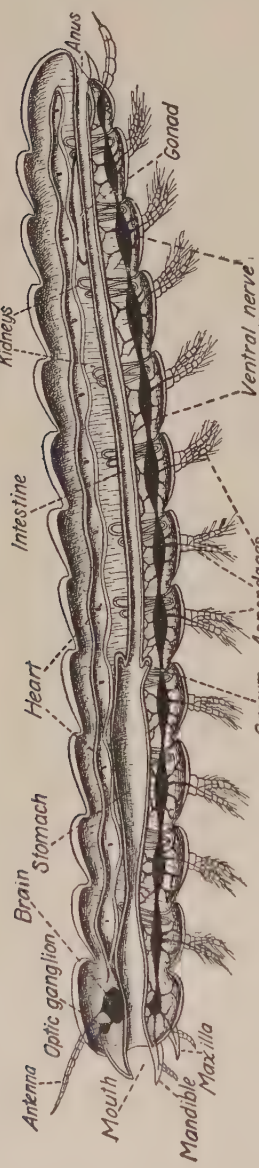


FIG. 27.—An hypothetical ancestor of the arthropods. Only the right side of the body is shown, and it is represented as if seen from the inside.

From such an ancestor the five existing classes of arthro-

pods probably arose and have become differentiated by specializing along particular lines. This does not mean that modern arthropods have necessarily become better than their remote ancestors. Specialization, in zoology, means that an animal is far from primitive ancestral conditions. Some specializations have been along progressive lines, others have made arthropods simpler in structure. Modifications have not taken place hit or miss in any direction, but have followed rather definite lines. The metameres of the body have been grouped into three regions—the head, thorax, and abdomen. In some cases the head and thorax have again fused so that there are only two regions—the cephalothorax and abdomen. The appendages have been greatly modified—in many instances one branch has been lost, so that an uniramous condition has come about; often the segments are lost, combined, or greatly changed in shape; sometimes the appendages are wholly absent from the abdomen. In most arthropods the ancestral number of mouth parts has been found to be insufficient and the walking legs just behind have been pressed into service. In one group five pairs of thoracic legs have been turned forward to help the mouth and only three are left for walking. The nervous system has shown a tendency to fusion—in some arthropods the ventral ganglia are no longer distinct but have fused into one great mass of nervous tissue. The sense organs (eyes, ears, etc.) have become very complicated in some cases. The kidneys seldom retained the primitive metameric arrangement but have usually been restricted to a single segment of the body, or wholly lost and replaced by a new type of excretory organ which opens into the intestine. The arthropods have, then, become specialized by losing parts of the body, by adding new organs, by condensation and combination, and in other ways—but all have retained the same general fundamental plan of structure, which shows that they are related.

As the arthropod line developed, it early split into two

groups. One remained aquatic, finally developing gills for respiration in the water, and gave rise to the class Crustacea. All the other arthropods became terrestrial and were hence

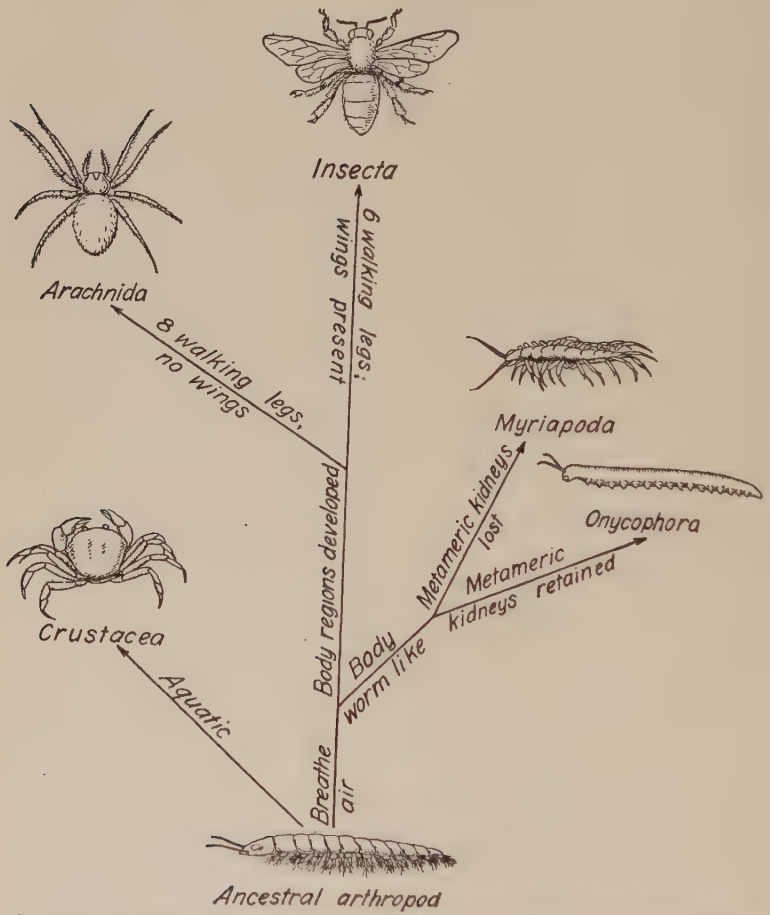


Fig. 28.—A scheme to show how the arthropods have developed from their ancient ancestor. The branches are not intended to represent actual relationships, but to indicate the lines of specialization which have been followed.

obliged to acquire the ability to breathe air. Most of the air-breathing arthropods have developed a branching system of minute tubes, the tracheæ, which carry air to

all parts of the body. We can, therefore, make two divisions of the Phylum Arthropoda:

Division I. Branchiata—breathing in water, through the general surface of the body or through gills.
Division II. Tracheata—breathing air, through tracheæ or in some other way.

The first division contains only the class Crustacea, and the Tracheata therefore include the other four classes. Two of the latter have retained the ancestral worm-like form, with metameric appendages, but are easily differentiated from each other because one class (Myriapoda) has lost the primitive metameric kidneys completely and the other has retained them (Onycophora). The other two classes have departed from the primitive worm-like form and are highly specialized. They have lost the appendages on the posterior end of the body; lost the metameric kidneys and developed a new type of excretory organ (the Malpighian tubules); and become specialized in many other ways. One of these last two classes (Insecta) has kept only six walking legs and has developed wings, the other (Arachnida) has retained eight walking legs and never possesses wings. We may at present, therefore, classify the Phylum Arthropoda on the following basis:

Division I. Branchiata. Aquatic, breathe through skin or gills.
Class 1. Crustacea. Aquatic arthropods, with primitive but non-metameric kidneys.
Division II. Tracheata. Terrestrial (or aquatic), breathe air, usually through tracheæ.
Class 2. Onycophora. Worm-like, with paired metameric kidneys throughout the body.
Class 3. Myriapoda. Worm-like; excretion through Malpighian tubules which open into the intestine just behind the stomach.
Class 4. Insecta. Three pairs of walking legs; one or two pairs of wings usually present; no metameric kidneys, Malpighian tubules present.
Class 5. Arachnida. Four pairs of walking legs; no wings; Malpighian tubules present.

The relationships of the classes of arthropods are shown in Fig. 28. Let us now consider each of them in more detail. The remainder of this chapter will be devoted to the Crustacea.

CLASS 1. CRUSTACEA

This class may be defined as including arthropods which live for the most part in water, and usually breathe through gills. We can perhaps best get an idea of one of these animals by considering the activities of an example which is familiar to everyone—the common crayfish, or crawfish,

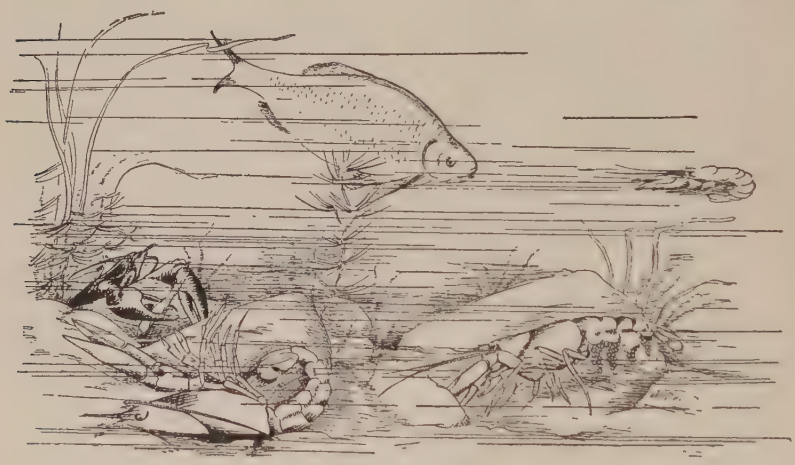


FIG. 29.—Crayfishes.

found in fresh water the world over. The daily life of this, or any other, animal is shaped primarily for three ends—self-maintenance, self-protection, and race preservation. To use the words of Alcock—"the three great exigencies: to find something to eat, to avoid being oneself eaten, and to disseminate one's species, give rise to a perpetual struggle in which the fittest is successful."

THE CRAYFISH, *Cambarus virilis* Hagen

Self-maintenance.—Crayfishes (Fig. 29) eat nearly anything that is available. They prefer animal food, and lurk

in sheltered nooks waiting for some unwary fish or insect to swim by. They catch such animals in their big pinchers, or chelipeds, and tear them to pieces. If living animal food fails, crayfishes eat plants, or any sort of dead organic matter—and are hence good scavengers. Fine particles of food are retained by the little bristles along the margins of the chelipeds and the mouth parts, so that nothing of value is lost.

A crayfish is well equipped with sense organs to find its food. There are two pairs of antennæ at the anterior end of the body and the shorter pair, the antennules, is not only provided with sensory bristles for receiving touch stimuli, but possesses organs of smell as well. A crayfish is able to taste with the nerve endings on the mouth parts. The compound eyes are set on stalks so that they can be moved about in different directions. Each is made up of hundreds of minute but complete eyes. Together these little eyes permit a crayfish to see a complete but somewhat broken picture of its surroundings—a mosaic image. If a crayfish is blind in one of its simple eyes, there is a space in its field of vision where nothing is visible.

Once the food is secured, it must be converted into living substance or modified so as to serve as fuel to run the living machine. It is pulled apart by the chelipeds, torn into shreds by the mouth parts, then passes down into the stomach, where it is further chewed by three strong projecting teeth and strained between little bristles. It is mixed with the digestive secretion from the "liver" and finally absorbed through the walls of the intestine. What cannot be digested and absorbed passes out of the anus as fæces. The digested food which passes through the wall of the alimentary canal enters great blood spaces, the sinuses, and ultimately reaches the small muscular heart, in the middle of the back, which pumps blood to all parts of the body. The heart works only when it contracts. It is passive during expansion, being stretched out by little elastic strands which lead from it to the walls of the chamber in which it lies. The blood of the

crayfish is colorless, but carries food, oxygen, and waste products.

A crayfish labors under one great disadvantage—the exoskeleton is so rigid that it cannot grow from day to day, as do animals with pliable skins. This shell is an admirable protection but prohibits growth. This difficulty is surmounted by a periodical casting of the entire exoskeleton—including the lining of the esophagus and stomach. After such a moult the crayfish is a "soft shell" for a day. During this period the body absorbs a great deal of water, and there is very rapid increase in size. The shell then hardens and no more growth can take place until the next moult. Just before the shell is shed a little stony secretion, the gastrolith, is formed on either side of the stomach. This is a reserve supply of lime which is rapidly transferred by the blood to the new shell after moulting.

The crayfish has a special respiratory system for securing oxygen, which consists of a number of plume-like gills along the sides of the thorax. These delicate breathing organs are protected by the hard shell, or carapace, which covers the cephalothorax. One of the mouth parts has a little paddle which projects into the respiratory chamber and by its movements keeps a current of water passing forward over the gills and out under the head. The gills are full of moving blood which receives oxygen from the passing water. The carapace fits over the thorax much as a man's coat covers his body, and the gill chamber is kept from getting dirty by little bristles along its edge which strain the incoming water.

The excretions resulting from general metabolism in the crayfishes' body are eliminated through the "green gland" —a form of kidney consisting of a long tube which is expanded into a bladder near the discharging end. Excretions are absorbed from the blood by the green gland and passed out through a pore which opens through the basal segment of the second antenna. There is only one pair of green glands and these are wholly within the head.

From what has been said, it is apparent that a crayfish is well able to find substances fit for food and to reject that which is unfit. Elaborate and specialized systems of organs for digestion, assimilation, circulation, respiration, and excretion are present.

Self-protection.—The solitary crayfish has many enemies—fish which seek to devour it, parasites which suck its blood or sap its vitality by infesting the interior of the body, minute moulds or bacteria which cause diseased conditions. How does it escape these?

Larger enemies are usually avoided by hiding in crevices between stones or water plants. If a crayfish is dislodged from its retreat, it swims quickly backward by flipping the powerful tail fin and often finds a new hiding place (Fig. 29). But if captured, it does not surrender without a struggle. The great claws inflict painful wounds and the smaller legs scratch—the cornered animal fights literally "tooth and toenail," until it is bested or escapes. Even if a leg or two is lost the damage is not serious for a new one is formed beneath the exoskeleton, and after the next moult is nearly as large as before. On account of the large spaces within the body, a crayfish easily bleeds to death if the body wall is punctured. In the appendages, however, excessive bleeding is prevented by a special arrangement. A crushed leg is thrown off at a "casting joint" near its base, where there is a very small aperture from the blood sinuses and the opening quickly closes.

The color of a crayfish is usually more or less like the surroundings, and can be changed somewhat by the contraction or expansion of little pigment cells in the skin. Such "protective resemblance" makes it less conspicuous.

The insidious enemies which attack the crayfish as parasites are warded off chiefly by sanitary measures. Scrupulous cleanliness is observed. There are special combs and bristles on the appendages for cleaning the exoskeleton and it is continually scraped and polished. If there is a break in the outside covering, the way is opened for various

moulds and bacteria to gain an entrance. These are fought off by little motile cells, the amœbocytes, until the wound can heal.

But a crayfish must struggle against other things besides aggressive enemies and stealthy parasites. It is obliged to meet the changing conditions of environment so as not to be destroyed by storms, or cold, or other unfavorable variations. Crayfishes are resistant to low temperatures and live a slow, yet active, life beneath the ice where there is a winter season. They do not fare so well if the water becomes too warm, and are therefore less abundant in the tropics than elsewhere. They can live for a considerable time out of water, particularly if they can rest in some damp place, as among fallen leaves.

Crayfishes quickly succumb to foul water and sometimes migrate over the land to escape from a stagnant pool. If the pond in which they have been living dries up, they burrow into the soil and remain quiet until water is again available. Some crayfishes have become expert diggers and make burrows far from water; in fact, some enter the water only during the breeding season. Such species often do damage by making holes in fields or by perforating dykes. They are easily killed by dropping unslaked lime down their burrows and closing them tightly.

Race Preservation.—Crayfishes are of separate sexes. Mature males are readily distinguished from females by their larger chelipeds and narrower abdomens. The reproductive gland, or testis, of the male lies in the posterior portion of the thorax and is connected by two tortuous ducts, the vasa deferentia, with small pores in the basal joints of the last pair of walking legs. The first two pairs of abdominal appendages in the male are peculiarly modified so that they may be used in transferring sperm to the female.

During the breeding season the males move about actively in search of females. When one is encountered, a little packet (the spermatophore) full of sperm cells is

transferred to her. In some species the females have a small pouch in the exoskeleton (the annulus) into which the spermatophore is thrust by the male.

A female has an ovary in the thorax which connects by two short ducts with openings in the basal segments of the third pair of walking legs. After receiving a spermatophore she prepares with great care to lay eggs. The abdomen and its appendages are cleaned for two or three days by scraping them with the last pair of walking legs. The female then lies on her side, bends the abdomen a little, and secretes a gelatinous apron over the underside of the body (Fig. 29). The eggs are then ejected from the opening in the third legs; the spermatophore dissolves and the sperm cells "fertilize" the eggs inside the gelatinous apron.

The jelly of the apron soon shrivels and breaks up; the eggs becoming fixed to the abdominal appendages by little stalks. The mother crayfish takes good care of the eggs; they are kept clean and frequently aerated by elevating the abdomen and waving the appendages which bear them (Fig. 29). There is yolk material stored within each egg-shell to nourish the developing embryo until it hatches. When the little crayfish emerges, it is attached to the old egg-shell by a slender filament which issues from the anus. It remains thus fastened to the mother even after its first moult (Fig. 30), but when the skin is shed the second time, the little creature is free and soon able to shift for itself. A female crayfish carries from three to six hundred eggs at a time and after becoming mature usually breeds annually. A crayfish usually lives to be six or seven years old.

A mature crayfish reacts to its surroundings so as to be successful as long as possible, and thus continue its race. How much mental ability does it display in responding to the stimuli which it receives? Very little. Its behavior is largely made up of reflexes and instinctive activities. If a large object appears in its field of vision, the crayfish crouches down into its crevice; if a small animal moves,

it rushes forth, seizes the intruder and tries to eat it. When hunger is satisfied the crayfish sits in its lair without any movement, except for respiration, for days at a time. Its activities are for the most part strictly utilitarian. Yet a crayfish has some ability to profit by experience. If a large shadow is cast over one repeatedly, it first avoids the shadow at each repetition and puts itself in an attitude for defense, but finally learns to ignore this new thing which has come into its life. Professor Yerkes taught a crayfish to go

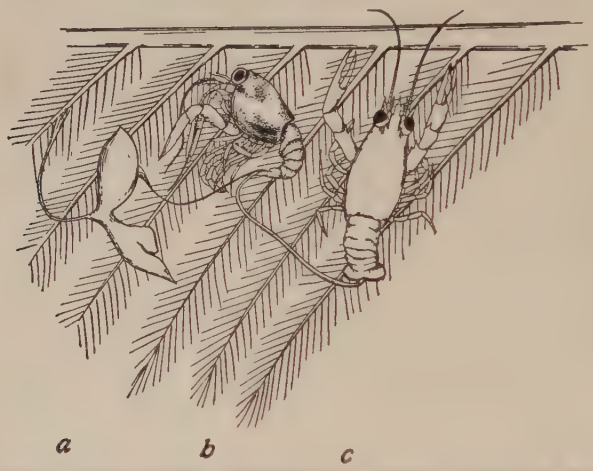


FIG. 30.—A young crayfish attached to a portion of one of its mother's abdominal appendages. Until after its second moult the young crayfish is firmly fastened by an "anal filament." (*Adapted from Andrews.*)

through a simple labyrinth where it had equal chance to enter a blind alley or to go through an opening into the water. At first it took the wrong course half of the time, but after two hundred and fifty trials made no more mistakes.

If we compare a crayfish with the ancestral arthropod described at the beginning of this chapter, we see that it is specialized in several respects. The abdomen is the most primitive part of the body, being clearly metameric with a pair of biramous appendages on each segment. The thorax is overgrown by the great carapace and shows evi-

dence of segmentation only on the ventral side. The thoracic appendages are specialized; most of them have lost the outer branch and become uniramous. Yet with careful examination in the laboratory we can demonstrate that a fundamentally similar plan of structure is shown by all of the appendages on the body of the crayfish, except the eye. If time permitted it would be possible to show many other ways in which the crayfish is specialized, but we must pass on to consider some of its relatives.

CLASSIFICATION OF CRUSTACEA

The Crustacea have in their specialization followed various lines and we can divide the class into two great groups, or subclasses, and a large number of orders. It will probably not be profitable for the student to try to learn the following list, but it is given in full in order that one may be able to see for himself what a degree of diversity has been attained in this most primitive class of arthropods, containing only about 16,000 living species. Before we pass to the table of classification it will be well to point out the chief lines which specialization has followed:

1. The heart has been greatly shortened so that in some crustaceans it occupies only one or two metameres.
2. The kidneys are always restricted to one pair.
3. Gills may be developed along the sides of the thorax, or on the thoracic or abdominal appendages.
4. The primitive biramous appendage is frequently modified by the dropping out of the external ramus or by the loss of segments.
5. A carapace may be developed. This may cover only a part or the whole of the thorax, or be large enough to enclose the entire body.
6. There is a tendency to acquire mouth parts at the expense of the walking legs.
7. The appendages are often lost on the abdomen.
8. The eyes sometimes become stalked.

With these points in mind let us pass on to the classification of the Crustacea.

Trilobita.—This group of extinct arthropods was ex-

tremely variable, the number of body segments ranging from four to thirty-one. Antennæ, compound eyes, and biramous appendages were present. All trilobites were marine and none have been alive for the past several million years. Recent Crustacea are classified as follows:

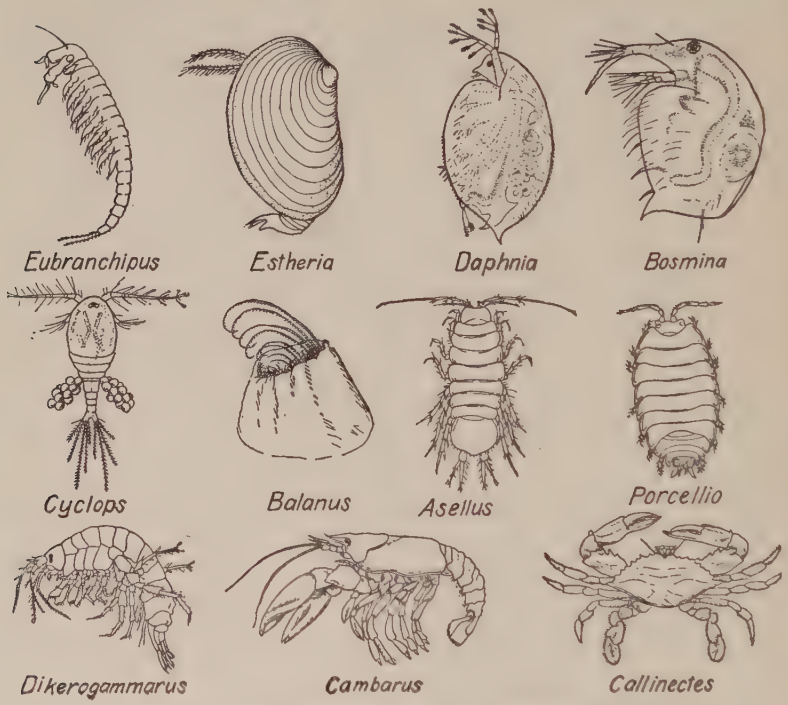


Fig. 31.—Examples of the Class Crustacea.

Subclass I. **Entomostraca.**—Number of metameres variable; kidney opens in base of maxillæ; no gastric mill in stomach.

Order 1. Phyllopoda.—With ten to thirty pairs of leaf-like feet; a carapace often present. Examples: *Eubranchipus*, *Estheria* (Fig. 31).

Order 2. Cladocera.—Second antennæ large, biramous, and used for swimming; body usually enclosed in a bivalve shell. Examples: *Daphnia*, *Bosmina* (Fig. 31).

Order 3. Ostracoda.—Only seven pairs of appendages. Body completely enclosed in a bivalve shell. Example: *Cypris* (Fig. 32).

Order 4. Copepoda.—With large uniramous antennæ which are used for swimming; abdomen without metameric appendages. Examples: *Cyclops* (Fig. 31), *Diaptomus*.

Order 5. Cirripedia.—Fixed or parasitic; body enclosed in a calcareous, non-metameric shell; barnacles. Example: *Balanus* (Fig. 31).

Subclass 2. **Malacostraca.**—Usually of large size; with five metameres in the head, eight in the thorax, and six in the abdomen; with a grinding apparatus, the gastric-mill, in the stomach.

Order 6. Nebaliacea.—Small shrimp-like, marine crustaceans, with an extra metamere in the abdomen; carapace well developed.

Order 7. Anaspidacea.—With distinct thoracic segments, stalked eyes, and no carapace.

Order 8. Mysidacea.—Small shrimp-like crustaceans; with biramous thoracic legs, and a large carapace.

Order 9. Cumacea.—Malacostraca without abdominal appendages, with a small carapace and four or five free thoracic segments.

Order 10. Tanaidacea.—Malacostraca with all but two thoracic segments free; respiratory chambers on sides of thorax.

Order 11. Isopoda.—Body usually broad and flat; no carapace; seven free thoracic segments. Examples: *Asellus*, *Porcellio* (Fig. 31).

Order 12. Amphipoda.—Body usually laterally compressed; with seven free thoracic segments; usually with three pairs of appendages fitted for jumping at the posterior end. Example: *Dikerogammarus* (Fig. 31).

Order 13. Euphausiacea.—Thorax covered by carapace; with respiratory chambers at sides; no thoracic legs serve as mouth parts.

Order 14. Decapoda.—With first three pairs of thoracic appendages specialized as mouth parts; ten walking legs; carapace covers thorax; stalked eyes.

Suborder 1. *Natantia.*—Slender, laterally compressed; abdomen well developed and provided with appendages. Examples: *Cambarus* (Fig. 31), lobster, shrimps, prawns.

Suborder 2. *Reptantia.*—Flattened, short; abdomen small and folded forward under thorax. Examples: *Callinectes* (Fig. 31), crabs.

Order 15. Stomatopoda.—Five pairs of thoracic limbs serve as mouth parts; six biramous walking legs; carapace covers only part of thorax.

LAW OF BIOGENESIS

The Crustacea may well serve to illustrate one of the great principles of zoology—are particularly appropriate, in fact, because the law in question was first discovered while the classification of this class was being investigated. The "Law of Biogenesis," otherwise known as the "Recapitulation Theory," holds that ontogeny repeats phylogeny—*i.e.*, that each individual animal in its development repeats the stages through which its race has passed in its evolution. Huxley once put the idea briefly by saying: "Every animal climbs its own ancestral tree."

This law has been of great value to zoologists in helping to work out the true relationships of animals. For example, because man, in his early embryonic development, has gill-like structures at the sides of his neck and a fish-like form, it is believed that he came from what was once a fish-like ancestor which lived in the water. Furthermore, it seems reasonable to believe that all vertebrates came from a common ancestry, because, up to a certain point, the developmental history of all is very similar. The embryonic record is often dim, or warped. There are instances where stages which should come later are sometimes pushed ahead, and embryonic animals sometimes acquire new specializations which their remote ancestors did not possess, but the great landmarks in the embryonic records generally keep their resemblance to the racial, or phylogenetic, history so that the story is readable.

The value of the Law of Biogenesis is well illustrated in the Crustacea. The barnacles, for example, were until a short time ago of very questionable relationships. Some zoologists believed that they should be placed with the molluscs because they had a hard shell, others that they should be classed with the worms, but no one thought of relating them to crustaceans. Then it was discovered that many entomostracans hatch from the egg as a little six-legged larva, the nauplius. This nauplius larva swims

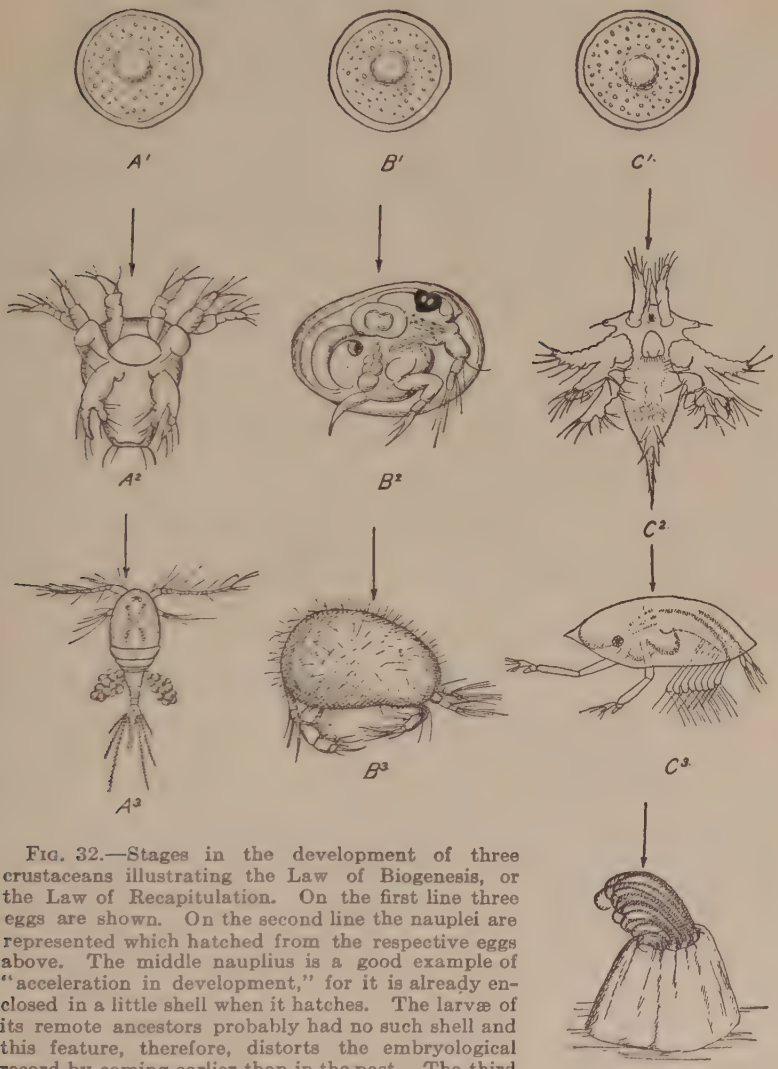


FIG. 32.—Stages in the development of three crustaceans illustrating the Law of Biogenesis, or the Law of Recapitulation. On the first line three eggs are shown. On the second line the nauplei are represented which hatched from the respective eggs above. The middle nauplius is a good example of "acceleration in development," for it is already enclosed in a little shell when it hatches. The larvæ of its remote ancestors probably had no such shell and this feature, therefore, distorts the embryological record by coming earlier than in the past. The third line represents the adult stages of the first two crustaceans (A^3, B^3) and what was at one time probably the adult stage in the ancestors of the third (C^3). The lower figure shows that the free stage shown in the line above has been succeeded by a fixed, or sessile, condition. This last change is accompanied by some degeneration. *A*, *Cyclops*; *B*, *Cypris*; *C*, *Balanus*.

around in the water until it has moulted its skin a few times, then takes on the form characteristic for its particular species. After the nauplius stage some kinds of crustaceans become Copepoda, others Ostracoda, etc., but all agree pretty closely up to the time when their nauplius skin is shed. When the embryology of a barnacle came to be studied—it hatched from the egg as a nauplius! Since this fact was discovered zoologists have not questioned the right of barnacles to be known as relatives of Cyclops, Daphnia, and other crustaceans. The life history of a barnacle indicates that its race developed to a free swimming stage comparable to the adult forms of other entomostracans; then took up a sessile existence, specialized along new lines, and even degenerated somewhat because it led an inactive life. Fig. 32 shows larval and adult stages of the barnacle and two of its relatives.

CHAPTER VI

PHYLUM ARTHROPODA, CLASSES—ONYCOPHORA, MYRIAPODA, INSECTA

CLASS 2. ONYCOPHORA

The sole representatives of this class of arthropods are the sixty-odd species of the genus Peripatus. Peripati occur only in certain parts of the world—Northern Africa, Northern South America, Mexico, and some of the South Pacific islands. These peculiar worm-like animals live in rotten logs, in crevices in rocks, among fallen leaves, and

FIG. 33.—Peripatus entangling a cockroach in sticky threads squirted from two papillæ beneath its head.

in similar situations. Their food consists of small insects, spiders, etc. They entangle their prey in little sticky threads which are ejected from glands on two papillæ beneath the head (Fig. 33).

The body of Peripatus is cylindrical and worm-like. It has from seventeen to forty pairs of small legs, a pair of jointed antennæ, and an eye just beneath each antenna. A single pair of appendages have been modified to serve as mouth parts—these act as jaws and tear the food to pieces. Most species of Peripatus bring forth the young alive. There is no metamorphosis—the young resembling the parents in their general structure.

Peripatus is of great zoological interest because it is a "missing link." It has many points of marked resemblance to annelid worms, and at the same time possesses characteristics which make it unquestionably belong to the Phylum Arthropoda. The annelidan affinities are shown by: (1) the paired metameric nephridia (kidneys); (2) the presence of cilia in the reproductive organs; and (3) the general arrangement of the chief systems of organs. Arthropod characteristics are: (1) appendages modified as jaws; (2) a body cavity mostly converted into large blood sinuses; (3) the presence of tracheæ for breathing; and (4) the paired jointed appendages. Peripatus closely resembles the hypothetical ancestral arthropod described at the beginning of Chapter 5 (Fig. 27).

CLASS 3. MYRIAPODA

This class includes the centipedes and millipeds (Fig. 34). These animals are readily distinguished from other

FIG. 34.—At the left a centipede eating a fly; at the right millipedes resting and eating a leaf.

arthropods by the following characteristics: (1) a distinct head with one pair of antennæ and simple eyes; (2) a long body composed of many free similar segments; (3) tracheæ for breathing; and (4) Malpighian tubules for excretory organs. The myriapods are divided into three orders:

Order 1. **Diplopoda.**—These are the millipeds. As the name of the order indicates, they have two pairs of jointed

legs on each segment; also, on the head, a pair of antennæ, a pair of mandibles, and one pair of maxillæ. Millipeds are usually cylindrical in form, but some species are flat. They are slow-moving sluggish creatures whose food consists entirely of vegetation. They often do damage to crops or greenhouse plants. *Julus* and *Polydesmus* are common genera.

Order 2. **Chilopoda.**—This order includes the centipedes, which have only one pair of legs on each metamere. The body is flat and has maxillipeds, which are a pair of modified legs, in addition to the antennæ, mandibles, and maxillæ mentioned as occurring in the last order. The

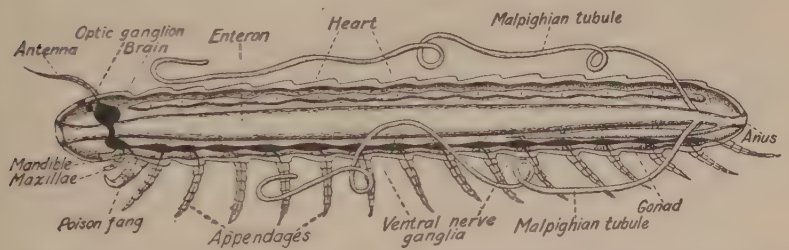


FIG. 35.—A centipede with the body wall and appendages of the left side removed to show the internal organs. Compare with Fig. 27.

maxillipeds in centipeds are poison claws. They have little openings at their tips which connect with poison glands within the body. The poison claws are used in killing small insects and spiders for food. The large tropical centipedes inflict painful bites, and have even been known to kill children.

Order 3. **Symphyla.**—These are small myriapods with only twelve pairs of legs. They are rare, but are of some theoretical interest because they resemble the most primitive insects (Aptera) in the structure of their mouth parts and in some other features.

Many of the myriapods remain with their eggs until they hatch. Some species build little nests by hollowing out a space in the ground or in a rotten log, or by plastering little pellets of mud together to make a dome-shaped case.

The Myriapoda (Fig. 35) show many points of progress when compared with our hypothetical ancestral arthropod (Fig. 27). The metameric kidneys have been lost and replaced by Malpighian tubules; tracheæ have been developed for breathing; the appendages are all uniramous except one pair of mouth parts; and the different orders show a progressive tendency to make walking legs into mouth parts.

CLASS 4. INSECTA

The class Insecta, once known as the Hexapoda (six legs), contains an enormous number of species—exceeding all the rest of the animal kingdom. The class is not only large but versatile as well. Insects show all sorts of peculiar adaptations for specialized modes of life. They are found in all parts of the world and live in almost every conceivable habitat. They vary in size from a twentieth of an inch to nearly seven inches in length.

The body of an insect has three distinct regions: head, thorax, and abdomen. The head bears a single pair of antennæ, usually two compound eyes, three simple eyes or ocelli, and four different kinds of mouth parts—the labrum, which is single and not one of the series of matemeric appendages; the mandibles, maxillæ, and labium, which are paired. The thorax is always composed of three segments—prothorax, mesothorax, metathorax. Each segment is protected by four exoskeletal plates—a dorsal tergum, a ventral sternum, and two lateral pleura. Each thoracic metamere bears a pair of walking legs, and each of the last two frequently bears a pair of wings. The abdomen typically consists of eleven free segments which are without appendages, except accessory reproductive organs or a sting at the posterior end.

The mouth parts vary greatly but conform mostly to two types: (1) for biting, as in a beetle; or (2) for sucking, as in a bug. Some insects, however, like the honey bee, may have very specialized mouth parts which may be used

for both biting and sucking. The walking legs have five parts: a proximal coxa, often fixed immovably to the sternum to which it is attached; a short trochanter; a long femur; a slender tibia; and a jointed tarsus which is usually provided with little hooks or pads at its free end. The legs may be adapted in various ways for grasping, swimming, digging, leaping, or other purposes. The wings arise as outgrowths from the two posterior thoracic segments. They are chiefly of two types: broad for sailing, as on a butterfly; and narrow for rapid propulsion, as on a house fly. They often bear scales or hairs. They may be thin and membranous, thick and heavy for protection, or vary in other ways. The little "veins" which traverse insects' wings are not primarily for carrying blood, but are thickenings serving as supporting or skeletal structures.

The inside of an insect's body is filled with digestive, reproductive, respiratory, circulatory, and excretory organs. The alimentary canal varies in its structure and extent according to food habits. Vegetarians have longer alimentary canals than other insects. The parts of the digestive system are: a mouth, or buccal cavity; a slender esophagus; a thin-walled crop; a glandular stomach from which little pouches, or cæca, branch out; and a long slender intestine. At the junction of the stomach and intestine the slender Malpighian tubules discharge their excretions into the alimentary canal.

The respiration of insects takes place through the tracheal system. This is a very much ramified network of tubes which carries oxygen to all parts of the body. The air enters the tracheæ through little openings, the spiracles, along the sides of the abdomen and thorax. An insect cannot be drowned by sticking his head in water; the spiracles must be covered before it will die. Good flyers have their tracheæ expanded into air sacs, which make the body light, but insects which fly little have no such expansions (Fig. 36). Aquatic species possess various modifications for breathing in water. They

either carry down air or absorb oxygen from the water through gills.

Insects usually hatch from eggs. As they grow the entire skin is shed at intervals. After each moult the body enlarges rapidly for a short time, but when the exoskeleton once hardens there is no more growing until the skin is shed again. Insects show three conditions of larval life and

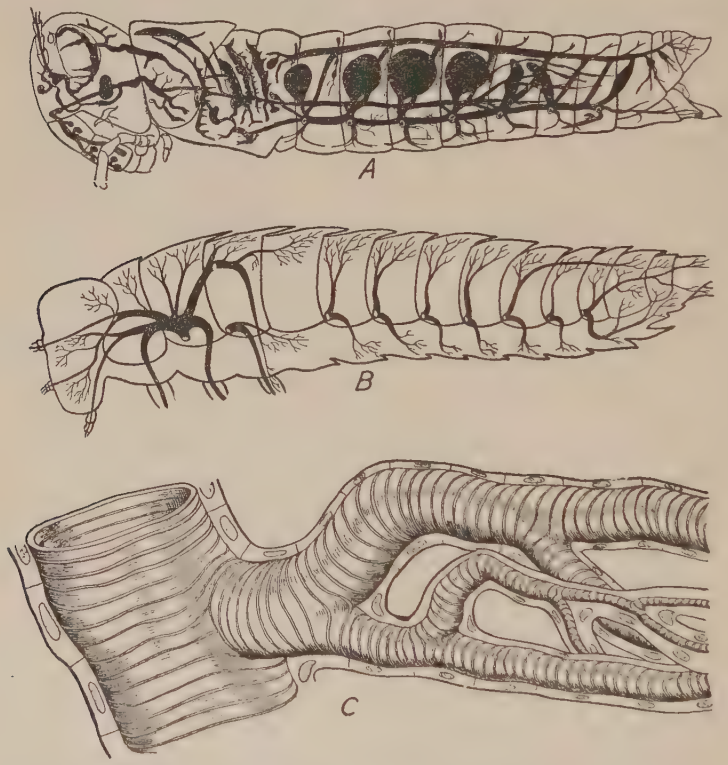


Fig. 36.—Insect respiratory systems. *A*, a flying insect with expansions, or air sacs, on the tracheal tubes; *B*, an insect which never flies; *C*, a portion of a tracheal tube enlarged.

metamorphosis. *Ametabolous* insects have no metamorphosis. They are much like the adult in form when hatched from the egg. *Heterometabolous* insects hatch as nymphs, which are at first wingless, but have gradually larger wings

after each moult, until the adult form is finally attained. *Holometabolous* insects have a "complete" metamorphosis. They hatch from the egg as a worm-like larva, which feeds for a time; then goes into a resting, or pupal, stage during which no food is taken. The larval structures are completely lost as the pupa is formed. When the pupa moults, an adult insect, or imago, comes out.

According to recent usage, insects are classified into nineteen orders. These will now be taken up in more or less detail.

Order 1. **Aptera** (Fig. 37).—These are little ametabolous, wingless insects with biting mouth parts. Wingless-

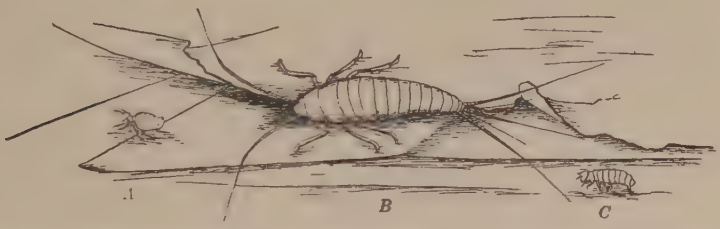


Fig. 37.—Insects belonging to the order Aptera. *A*, a collembolan; *B*, a slicker, or silver-fish; *C*, a spring-tail.

ness in this case represents a primitive condition. The little slickers, silver-fish, or fish moths; the spring-tails; and the snow-fleas are examples. Slickers eat the glazing on paper and starch from clothes. They are frequently seen in dwellings or factories. Spring-tails are expert jumpers, being able to hop many times their own length. The snow-fleas are sometimes so abundant as to give the snow a characteristic color.

Order 2. **Ephemerida** (Fig. 38).—The may-flies live near water. They are heterometabolous insects with biting mouth parts. Both the larval and adult may-fly are easily recognized by the long setæ which project from the end of the abdomen. There are three of these on the larva, and two or three on the adult. Eggs laid in the water hatch into nymphs which live for about a year, feeding on aquatic life.

A nymph when mature crawls out of the water, splits up the back, and an imago emerges from the old skin. The adult may-fly lives only a day or two and keeps fluttering along the shore, looking for a mate or laying eggs. Its mouth parts are so rudimentary that it is wholly unable to eat.

Order 3. **Odonata** (Fig. 38).—This order includes the dragon-flies and damsel-flies. Both are largely aquatic, lay

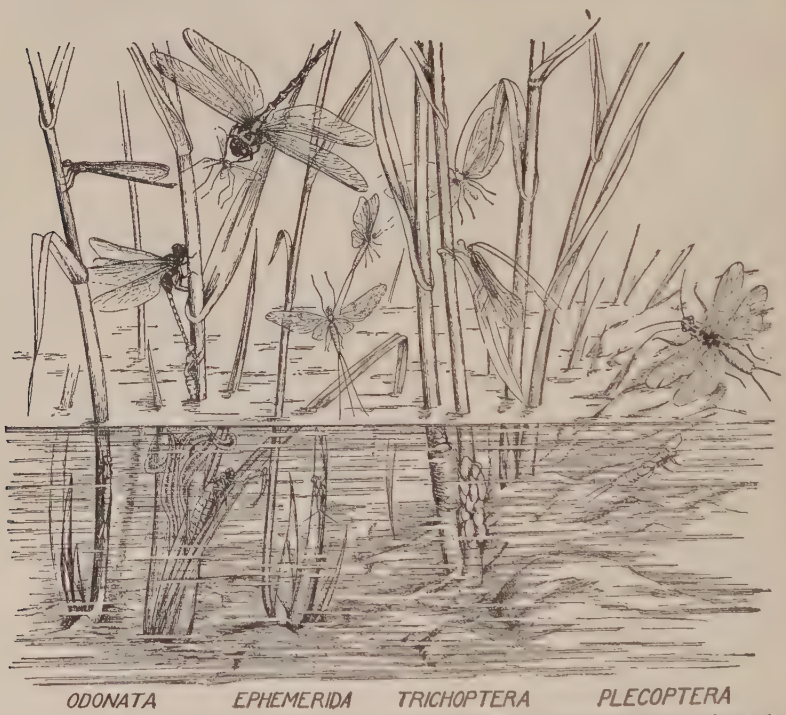


Fig. 38.—Showing the immature and adult stages of the four chief orders of aquatic insects.

their eggs in the water, and have a heterometabolous metamorphosis. Damsel-fly larvæ have three paddle-like gills at the end of the abdomen. The adults are sly little insects which fold their gauzy wings up over their backs when at rest. Dragon-fly larvæ have three short spines at the end of the abdomen. They swim by drawing water

in through the anus and then squirting the body forward. The adult dragon-flies rest with their wings stretched out on either side of the body. They are expert flyers and are of benefit to man on account of the great numbers of mosquitoes they destroy. A dragon-fly catches all its prey on the wing. Its enormous eyes cover the whole of the

Fig. 39.—Termite nests. At the right is a section of a tree and a carton nest; at the left a mound nest is shown.

head (30,000 facets are present in one species); its long light wings enable it to fly with great swiftness in any direction. The larvæ of all Odonata have a peculiar grasping lower lip, or labium, which can be greatly extended to capture food, or folded up like a hinge beneath the head when not in use.

Order 4. **Plecoptera** (Fig. 38).—The stone-flies are heterometabolous, aquatic insects, with biting mouth parts.

They get their name from the habit the larvæ have of hiding under stones.

Order 5. **Isoptera** (Fig. 39).—The termites, or white ants, have four leathery wings or are wingless, possess biting mouth parts, and are heterometabolous. They are most abundant in tropical countries where they do great damage to timber and wooden structures. They never come out in the light, but secretly dig burrows in wood until there is nothing left but a thin outside shell which finally falls into powder. Many species of termites make enormous nests which contain thousands of individuals living as a complex social community. Division of labor has been carried so far that there are as many as eight different castes in some species. These are females, males, workers, soldiers, etc. The worker and soldiers castes are sexually immature and may be either males or females. The female breaks off her wings after mating so that she may not stray from home. When mature she is a big helpless egg-laying sac, and must even be fed and cleaned by her nurses. She grows to be a thousand times as large as her mate.

Orders 6, 7, 8, 9. **Corrodentia,** book-lice and bark-lice; **Mallophaga,** biting bird lice; **Thysanoptera,** thrips; **Euplexoptera,** earwigs. All these insects have biting mouth parts, and are heterometabolous, except the Thysanoptera which have mouth parts somewhat modified for sucking and a peculiar metamorphosis in which there is a resting stage. Different species of thrips are pests on onion, wheat, grass, and fruit.

Order 10. **Orthoptera** (Fig. 40).—The cockroaches, walking-sticks, mantids, grasshoppers, locusts, katydids, and crickets are included in this order. These insects all have biting mouth parts and are heterometabolous. Most of them have four wings; the anterior pair being straight and leathery; the posterior pair, membranous and folding like a fan. There are six important families:

Family 1. *Blattidæ;* cockroaches. These insects have

the legs all about the same size and fitted for running. They are very swift and for the most part nocturnal. Their natural home is in rotten stumps or under loose bark. Around factories and apartment houses cockroaches often cause a good deal of trouble. Sometimes they carry diseases. A finely powdered mixture of equal parts of sugar and borax will kill them.

Family 2. *Acrididæ;* locusts, or "short-horned" grasshoppers. They have the hind legs greatly elongated for

Fig. 40.—Representatives of the chief families of Orthoptera. From left to right the insects are as follows: tree cricket (*Oecanthidæ*); katydids, female and male (*Locustidæ*); mole-cricket, field cricket (*Gryllidæ*); grasshoppers(*Acrididæ*); mantis and egg-mass (*Mantidæ*); cockroach and egg case (*Blattidæ*); walking-stick (*Phasmidæ*).

leaping. The name "short-horn" refers to the abbreviated antennæ, which are always shorter than the body. A representative of this family will be discussed in detail in the next two chapters.

Family 3. *Locustidæ;* long-horned grasshoppers, katydids and meadow grasshoppers. These orthopterans have

the antennæ longer than the body. Many show protective resemblance in color or form to the leaves among which they live.

Family 4. *Gryllidæ;* crickets. The mole-crickets have enormous front legs and spend their entire lives burrowing underground; the true crickets are the common varieties whose shrill chirps are heard in the fields or about houses; the tree crickets live above ground in vegetation and have very harsh, guttural voices.

Family 5. *Mantidæ;* praying mantids, devil-horses. In these insects the first pair of legs form prehensile organs which are used in capturing insects, spiders, etc. Mantids live in bushes or trees and are most abundant in the warmer parts of the earth.

Family 6. *Phasmidæ;* walking-sticks. These curious orthopterans have small legs suited for walking. Their form resembles the twigs on which they live. They are very slow and depend upon their protective resemblance to escape their enemies. If disturbed they often remain motionless for hours at a time, lest they betray themselves. Their food consists entirely of leaves.

The following key* will separate representatives of the Orthoptera into their proper families:

1 (6) Legs equal or nearly equal in size; no sound-producing organs (Suborder, Non-saltatoria), 2
2 (3) Body short, broad, oval, depressed; head almost wholly concealed beneath the thorax; legs compressed, Family, *Blattidæ*.
3 (2) Body elongate, narrow; head free, not covered by thorax; legs slender and not all compressed.....4
4 (5) Front pair of legs fitted for grasping.....Family, *Mantidæ*.
5 (4) Front pair of legs much like the others....Family, *Phasmidæ*.
6 (1) Hind legs fitted for leaping, or front legs greatly enlarged for burrowing; organs for producing sound usually present (Suborder, Saltatoria), 7

* In using the key the statement after a particular number is always to be compared with that appearing after the number in parenthesis, which occurs elsewhere in the key. For example: 1 is compared with 6, 2 with 3; 3 with 2, etc.

7 (8) Antennæ much shorter than the body; calling organs of male, when present, on the hind femora and lower border of first pair of wings; organs of hearing, when present, on the basal segment of abdomen; ovipositor short....Family, *Acrididæ*.

8 (7) Antennæ much longer than body, tapering; calling organs of male, when present, on the dorsal surface of the first pair of wings; organs of hearing, when present, on the tibiæ of the first pair of legs; ovipositor a long blade or needle.....9

9 (10) First pair of wings slope down from the dorso-median line; ovipositor compressed and sword-like....Family, *Locustidæ*.

10 (9) First pair of wings flat above, the sides bent abruptly downward; ovipositor a cylindrical, straight, or slightly curved needle, usually enlarged at the tip.....Family, *Gryllidæ*.

CHAPTER VII

PHYLUM ARTHROPODA, CLASS INSECTA, ORDER ORTHOPTERA

THE KINDS OF GRASSHOPPERS

Grasshoppers, or short-horned locusts (*Acrididæ*), are numerous the world over wherever appropriate conditions are found. There are about 550 species in the United States. Most of these do not range throughout the country—Indiana, for example, has only about 65 species within its borders. With such diversity it is necessary to have some means for dividing grasshoppers into groups or clans. Zoologists have accordingly separated the Family Acrididæ into four subfamilies, and these may be differentiated by the following key:

1 (2) Size small; first segment of thorax prolonged backward so that it reaches to, or even beyond, the posterior end of the abdomen; first pair of wings rudimentary. The grouse locusts Subfamily, *Tettiginæ*.

2 (1) Size larger; first segment of thorax never extending over the abdomen; first pair of wings usually well developed as tegmina, or wing-covers.....3

3 (6) No spine or tubercle on the sternum between the front pair of legs.....4

4 (5) Front of the head, or face, making a very oblique angle with the top of the head; wings never brightly colored and without a black band.....Subfamily, *Tryaxalinæ*.

5 (4) Face not forming a sharp angle with the top of the head; second pair of wings usually with some yellow, red or black Subfamily, *Œdipodinæ*.

6 (3) A distinct conical or cylindrical spine on the front margin of the sternum between the first pair of legs.....Subfamily, *Acridinæ*.

The grouse-locusts (*Tettiginæ*) are the smallest grass-

hoppers. They pass the winter as mature insects, hiding beneath stumps, logs, or rubbish. On sunny days, they sometimes venture out in great numbers, even in mid-winter. On the first warm days of spring they can be collected by hundreds from a grass-covered hillside having a southern exposure, or from boggy places along the margins of lakes and streams. They feed upon vegetable mould, humus, lichens, mosses, tender sprouts, etc. Grouse-locusts lay eggs underground in May, and the young which hatch from them mature by autumn.

The *Tryaxalinæ* for the most part frequent the borders of marshes and damp prairie meadows. Their noiseless flight and quiet colors render them rather inconspicuous. They pass the winter in the egg stage, mature during the summer, and die in the autumn. Many species have the wings short and imperfectly developed.

The subfamily *Œdipodinæ* includes many locusts that are familiar to everyone. In all these insects the body and outer wings are dull brown or gray. Such somber colors blend with the dusty roads and bare patches which they frequent. When in flight, however, the bright colors of the inner wings are displayed. The *Œdipodinæ* sing on the wing—making a peculiar crackling sound. They "crackle" and display their bright colors to attract mates, and such activities make them rather conspicuous. The Carolina Locust, *Dissosteira carolina,* is the common large species along roadways, its inner wings are black with a broad yellow border. A few of the grasshoppers in this family pass the winter as half-grown "nymphs," but most species winter over in the egg stage.

Most of our common small grasshoppers belong to the family *Acridinæ*. They vary much in size and general appearance. Among them are found our most injurious *Orthoptera* for they commonly feed on vegetation, such as farmers' crops. Most species are dull olive-brown, or green, frequently with stripes or spots, and none have brightly colored wings. Members of the same species may

vary in color in different localities or at different seasons of the year. The genus *Melanoplus* is the largest one in this group. Its representatives are to be found in grass, which is their chief food. The males of the *Acridinæ* usually sing when at rest and most of them rarely produce sounds at all. In order to get a concrete idea of the daily life of the grasshopper, we will now consider the activities of the red-legged locust.

Wheeler says: "An organism is a complex, definitely coördinated and, therefore, individualized system of activities, which are primarily directed to obtaining and assimilating substances from an environment, to producing other similar systems, known as offsprings, and to protecting the system itself and usually also its offspring from disturbances emanating from the environment. The three fundamental activities enumerated in this definition, namely nutrition, reproduction and protection, seem to have their inception in what we know, from exclusively subjective experience, as feelings of hunger, affection and fear respectively." The activities of the red-legged locust may properly be considered, therefore, under the topics: self-maintenance, self-protection, and race preservation.

You may wonder why anyone should study a grasshopper, or why the writer should think it would be profitable for you to do so. There are many reasons why it is desirable. It may be used to illustrate many general zoological facts and principles, with particular application to insect problems, and you may perhaps be glad after all that we did not choose elephants, or rattle snakes for illustrative material. If we are going to look into the daily life of the grasshopper, however—even pry into his pantry, cupboard, sleeping apartments, courting places, and other most private haunts—you must try to put yourself in friend grasshopper's place, and realize to the extent of your ability what his sensations, wants, and difficulties are. If we know a great deal about one animal, we will be prepared to make more rapid progress with others.

THE RED-LEGGED LOCUST, OR GRASSHOPPER

Melanoplus femur-rubrum DeGeer

Self-maintenance.—The grasshopper eats grass or almost any other vegetation. Its food is, therefore, abundant and easily found. If hungry, it gives a few hops this way and that, and finally lands in the midst of plenty. Once established on a blade of grass, its jaws start swinging sideways, and it chews away until satisfied. The strong mandibles, or jaws, bite off the grass. The other mouth parts help manipulate the food and pass it on into the esophagus, much as the lips and tongue help the teeth in handling our food.

The grasshopper is well provided with sense organs which may help it in finding and testing its food (Fig. 41). The antennæ are supplied with tactile bristles for feeling and olfactory pits for smelling. The sense of touch is very acute but smell is less developed than in insects like flies, which find their food by its odor. In addition to the olfactory pits of the antennæ, others occur on the body between the bases of the legs. On some of the mouth parts there are gustatory pits. These are organs of taste which test the palatability of the food before it enters the mouth.

There are five eyes on the head. The front bears three simple eyes, or ocelli; two near the bases of the antennæ and one near the center of the forehead. At the sides of the head are the great oval compound eyes, made up of thousands of six-sided ommatidia. Each ommatidium is a complete organ of vision, with a lens, pigment, a sensitive nerve ending, and nerve fiber connecting with the optic ganglion and the brain. A compound eye may see either a mosaic or an apposition image. In the first type there is a picture of the surroundings but it is broken up into a great number of small pieces, each of which is perceived by one ommatidium. In an apposition image the view in each ommatidium overlaps those adjacent to it so that

there is a continuous picture of the surroundings, probably as good in some respects as that seen by the human eye. The eyes of the grasshopper are not as acute as those of some other insects. The dragon-flies, for example, which catch their food on the wing have very sharp vision.

If a grasshopper eats all the available food in one place, it must either die of starvation or seek elsewhere. Its

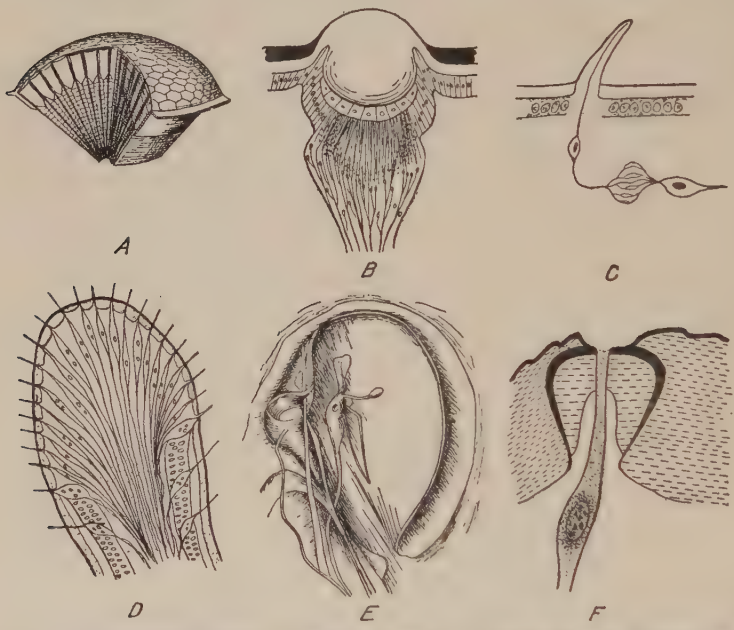


Fig. 41.—The sense organs of various insects. (*After Schmeil, Kellogg, vom Rath, Graber, McIndoo.*) *A*, a compound eye with a quarter removed; *B*, a section through an ocellus, or simple eye; *C*, a tactile bristle split lengthwise to show the nerve fiber within; *D*, section through an appendage covered with gustatory or taste bristles; *E*, internal view of a grasshopper's tympanum, showing a central ganglion and its nerve; *F*, section through an olfactory pit.

powers of locomotion are accordingly well developed. It usually crawls about slowly seeking favorable feeding grounds, but if it does not soon meet with success, resorts to hopping, or makes a flight to some distant spot. The claws and pads at the tips of its legs enable it to climb readily so that it can seek out the most desirable parts of plants.

The red-legged locust is strictly diurnal, and in this respect differs from its relatives, the crickets and katydids, which are most active at night. Early in the morning it walks about over the grass and eats the little drops of dew that have collected during the night. It is not able to drink standing water, and will usually die when kept in confinement unless drops are sprinkled about for it.

The digestive system of the grasshopper is well suited to handle the food which enters through the mouth. A pair of salivary glands pour their secretion into the mouth, and moisten the food so that it readily passes down the esophagus into the crop. Here it is mixed with the brown "molasses" or "tobacco-juice"—a digestive fluid. Behind the crop is a muscular gizzard, with little teeth on the inside. Here the food is further ground and mixed. Immediately behind the junction of the gizzard and the stomach proper, several cæca open into the alimentary canal. Each cæcum has an anterior and a posterior pocket. These spaces serve to increase the interior surface of the alimentary canal, and thus help digestion and absorption, as well as give more space for storage of food. The intestine leads directly from the stomach to the anus. It is divided into three parts: the ileum, a slender portion with longitudinal ridges on the inside for increasing its absorbing surface; the colon, smaller than the ileum and with a smooth lining; and the rectum, which has six longitudinal rectal glands of unknown function. The liquid portions of the food are absorbed through the walls of the intestine and the undigested residue passes out through the anus as fæces.

The food absorbed through the walls of the alimentary canal goes into the blood. The circulatory system of the grasshopper consists of a long tubular heart extending down the middle of the back just beneath the body wall, small arteries leading forward from the heart, and large irregular sinuses in all parts of the body. The heart pumps the blood forward and is partially divided into eight chambers.

Back flow of the blood is prevented by a series of little valves which allow only movement toward the head. After the blood traverses the sinuses (where it bathes all the internal organs, so that they may absorb nourishment from it and shed excretions into it), it flows into the pericardial chamber and enters the heart through several pairs of lateral ostia. If more food is digested and absorbed than can be utilized, it is converted into fatty substances and stored in the two elongated "fat bodies" on either side of the heart.

The blood of a grasshopper, or of any tracheate arthropod, does not carry oxygen or carbon dioxide as it does in most animals. The tracheæ form separate channels for carrying air and the respiratory system is, therefore, entirely independent of the circulatory system. This is an admirable scheme, for each system is free to carry on its own work. It has the disadvantage, of course, of requiring two separate systems of conducting tubes in all parts of the body. The grasshopper's tracheal system has good-sized air-sacs (Fig. 36), which indicate that it is well fitted for flight. When a grasshopper breathes rapidly the abdomen is rhythmically shortened and lengthened. By such movements air is forced in and out of the spiracles on the sides of the thorax and abdomen. A tracheal tube will not collapse, for the walls have an elastic strand in them which, though not continuous, is closely coiled like a wire spring and keeps them expanded. The tracheal tubes divide into very fine branches which go to every part of the body. They extend to the tips of the legs, are closely wrapped about all the internal organs and even penetrate into them. Oxygen is thus always at hand to help in metabolism.

The excretions resulting from metabolic processes in the grasshopper's body are eliminated through Malpighian tubules which open into the intestine (midgut) just behind the stomach. These tubules are closed at the free end. They are very slender and swing freely about in all directions in the blood sinuses. Waste products are absorbed

through their thin walls and discharged into the intestine. These waste products, which result from the breaking down of protein compounds (protoplasm), take the form of urea or of uric acid. Uric acid is a crystalline substance not soluble in water. Grasshoppers that live in very dry places, where they need all their water, have uric acid as their excretion product. Those which live in moist places excrete urea, which is dissolved in water and eliminated as urine.

CHAPTER VIII

PHYLUM ARTHROPODA, CLASS INSECTA, ORDER ORTHOPTERA

THE RED-LEGGED LOCUST (*Continued*)

Self-protection.—A grasshopper not only needs to secure food but must also escape from lurking enemies and other dangers if it is to be successful. Each obstacle must be met or avoided in a different way. The grasshopper, therefore, has many adaptations for enabling it to slip out of difficulties which might, in the absence of special measures, prove its undoing. The flight of red-legged grasshoppers is comparatively slow, but so erratic that birds have some difficulty in catching these insects on the wing. The grasshopper's method of escape from a pursuing enemy is to give a hop or make a short flight, then rest quietly for a time, and, if again threatened with immediate danger, to make another quick change of locality. Such tactics are continued until the grasshopper either escapes or is captured. An expert hunter, like a turkey, catches the grasshopper at the moment it alights, before there is time to start off again. Some species of grasshoppers are so swift, however, that they easily escape capture unless taken unawares.

When a grasshopper rests in its natural haunts, it is difficult to see, for each species is decked out to match its surroundings. There may be green to simulate the grass, dark bands to resemble the shadows among the vegetation, or an arrangement of colors to obliterate the outline of the grasshopper's body so as to make it look like something else. It is, of course, a great advantage to be protectively colored, and the grasshopper's attitudes make its resemblance to

its surroundings more complete. When at rest the body is held parallel with a blade of grass so as to be easily overlooked. Often a grasshopper that has been sitting in some careless attitude may be seen to change its position when danger approaches. The body is whirled around so as to lie along a grass blade in a crouching position—ready, set for a jump at a moment's notice. Our red-legged locust

FIG. 42.—The activities of grasshoppers. *A*, being captured by a robber fly; *B*, flying; *C*, dead with fungus disease; *D*, caught by a spider; *E*, laying eggs *F*, captured by a digger wasp; *G*, *H*, *I*, nymphs.

has a touch of yellow and brown so that it may go unseen among the dead grass. When caught napping in the green foliage, it at once falls head over heels to the ground where it is more likely to escape notice. Some relatives of the grasshopper show extreme cases of protective resemblance. Certain katydids, and "leaf-insects" have in their bodies reproduced the color and form of the leaves they frequent,

even to the picturing of midribs, veins, and other fine details.

Suppose, though, that our stupid grasshopper's simple wiles are of no avail, and that it is caught by an enemy. It does not give up without a struggle—kicks, and strains to the best of its powers in efforts to escape. If it is held by only one leg this appendage is kicked free from his body and gladly left in the enemy's hands. It is a small matter for a young grasshopper to lose a leg; somewhat inconvenient for a time, perhaps, but no serious consequences result. A new leg is formed beneath the exoskeleton and becomes functional at the next moult. An adult grasshopper, however, cannot grow new legs.

Often when captured, in the excitement of the resulting struggle, a grasshopper forms great quantities of the brown "molasses," or crop secretion, which drools from the mouth. Such secretory activity is somewhat comparable to the formation of "cold sweat" on the skin of man during certain emotional states. In the present instance, the molasses sometimes serves a useful purpose by making the grasshopper distasteful to the animal holding it captive.

Grasshoppers are comparatively soft-bodied and of good flavor. They are hence sought for food by a great number of animals, even including man in some parts of the world. They are not even safe when they settle down to rest at the close of a day, for the night-prowling skunk esteems grasshoppers a great delicacy, and seeks them out during the night. In his work on the Orthoptera of Indiana, Blatchley lists forty-nine birds which feed upon grasshoppers in that state. Chief among these are hawks, blackbirds, crows, bluejays, prairie chickens, mocking birds, and bluebirds. Many snakes feed very largely on grasshoppers, and their sly habits make them hard to avoid. Toads, frogs, and some fish also prey upon these insects when the opportunity offers. Moles and shrews eat the eggs laid by grasshoppers underground.

There are many arthropods which use grasshoppers for food (Fig. 42). The large orb-weaving spiders spread their snares in the low vegetation. Small mites lurk beneath leaves, waiting to attach themselves to some unwary grasshopper and suck his blood. Fierce robber-flies dart over the fields; ever ready to pounce down and carry a grasshopper to some retreat to be devoured at leisure. The wasps and beetles are also important enemies among the insects. Some wasps store their nests with nothing but grasshoppers.

All the enemies mentioned up to this time seek to devour the grasshopper, piecemeal or *in toto*. We have now to consider certain animals which invade the interior of the body and live as parasites.

Often on a hot day you may see a lazy grasshopper flap slowly along, changing his feeding ground. In the midst of his course he is pursued and touched for an instant by a swift little fly, which then goes about its business. This is a tachina-fly, and it needs only a fraction of a second to poke an egg between the segments of the grasshopper's abdomen. The egg hatches into a maggot which straightway begins to bore his way into and through the interior of the grasshopper, feeding as it goes. The vital organs are left until the last, so the grasshopper drags out a miserable existence as a living hotel for this voracious larva. Some flesh-flies also lay their eggs in grasshoppers when they have a chance. Certain of the horsehair worms likewise live for a part of their life cycles in these abundant insects.

The grasshopper, like man, is subject to certain diseases which make it sick or even cause death. These are, in addition to the large parasites already mentioned, mostly caused by bacteria and parasitic fungi. Such pathogenic organisms are more abundant, and hence more easily acquired, during damp weather. Wet seasons are, therefore, undesirable for the grasshopper but good for the farmer. Parasitic plants, such as bacteria, are able to enter the body more readily if there is a wound on the

surface, so that they can get through the exoskeleton, which usually gives protection to the internal organs.

Perhaps enough has been said to show that the grasshopper pays the penalty for being abundant and, as insects go, to a reasonable degree successful. It is beset by a host of enemies which in various ways try to make an end of it. If we have "put ourselves in the grasshopper's place," we may now feel a certain sympathy for the creature—but there is another side to its case. If grasshoppers have a good season, with abundant food, few enemies and favorable meterological conditions, it will be a bad year for crops. In many parts of the United States in fact, the grasshopper is successful enough to be a continual menace, and in some seasons becomes a veritable calamity. This has led man to devise means for his own protection, and these have been developed along four lines: (1) traps, (2) poisonous sprays, (3) inoculation with diseases or the introduction of natural enemies, and (4) poison baits.

On certain crops, grasshoppers may be killed by using sprays (arsenate of lead, Paris green, kerosene, etc.). Their method of feeding renders them readily susceptible to poisons sprayed on the outside of plants. Oils, like kerosene, enter the tracheal tubes and kill in that way. Such methods are not, however, readily practised on a comprehensive scale. In large fields trapping is often resorted to as a means of control. One method is to set large cans of water and kerosene below the surface of the ground in places where the insects are most abundant. In hopping about the grasshoppers fall into the traps and are killed. The hopperdozer (Fig. 43) is a movable trap which is driven over infected fields. The grasshoppers hop or fly as it comes near, fall into the kerosene pan, and die.

In the way of living enemies, a flock of turkeys will do as efficient work as any remedy. Other measures consist in the introduction of parasitic flies, or in the liberation

of grasshoppers already infected with contagious diseases. Several years ago a plague of locusts was successfully fought in Argentina by liberating a fungous disease. More recently in New Mexico a fly, *Sarcophaga kellyi*, "was found to be by far the most important factor in control." Some wild birds (horned lark, meadow lark, sparrow hawk, kildeer, quail) also served as loyal allies of man on this occasion.

The great "plagues" of grasshoppers in the United States have in most cases been due to the ravages of the migratory locust, *Melanoplus spretus*, which travels in enormous flocks

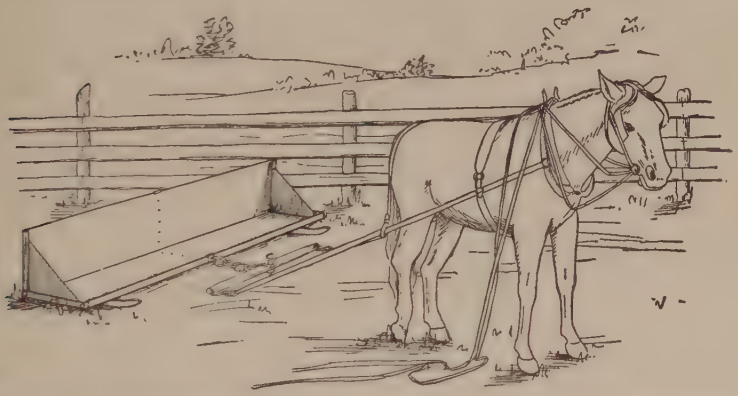


FIG. 43.—A hopperdozer. Kerosene is placed in the trough which is then dragged over a field.

through the high prairies of Western Kansas, Nebraska, and Eastern Colorado. In the plague of 1913, another species, *Dissosteira longipennis*, was so abundant that it repeatedly stopped trains by massing on the railroad tracks. It rendered an area of 500 square miles unfit for grazing. Grasshoppers not only harm man by feeding on crops, but do injury by spreading the spores of various plant diseases.

If a grasshopper successfully escapes all its enemies, it still cannot rest in idle ease, but must make continual adjustments to the changing conditions in its surroundings. During rains the big head and roof-like wings protect it

somewhat, but wet weather is bad for grasshoppers for then diseases multiply and other difficulties arise. A few grasshoppers pass the winter as adults, or half-grown nymphs. The red-legged locust, however, gives up the struggle in the autumn, but before dying lays a mass of eggs which hatch in the following spring. This brings us to the last aspect of the grasshopper's life—race preservation.

Race Preservation.—Grasshoppers are of separate sexes, males and females. A female is readily distinguished externally by the ovipositor, or "egg-layer," at the tip of the abdomen. This is composed of two short curved horny plates, which cover the opening for the genital organs. The internal reproductive organs in a female grasshopper's abdomen consist of a series of long tubes modified in different regions to form a pair of ovaries, oviducts, shell glands, and a seminal receptacle. The ovaries are glands which give off living egg cells. Each consists of a number of little tubes which connect with the oviduct. A male has in his abdomen a pair of testes which produce sperm cells, and two long twisted *vasa deferentia*, or sperm ducts. Extending at the posterior end are a pair of cerci for introducing sperm into the female.

If red-legged locusts are to eat grass year after year there must be a continual series of new generations. These are produced in only one way—from eggs. A female grasshopper can grow eggs by herself and even lay them in some cases, but the eggs will not hatch out young grasshoppers unless they have been fertilized. "Fertilization" consists primarily in the union of a sperm cell nucleus with that in an egg cell. In order to insure fertilization the two sexes must be brought together.

The coming together of the male and female grasshopper is not altogether a matter of accident. The male takes the initiative. If you sit quietly by a dusty road on a summer day, you cannot fail to observe the Carolina locusts. The males at intervals rise from the ground, flap their wings

for a minute, and then settle down again. The "flapping" is to notify females that an amorous male is abroad. It displays the yellow and black of the under wings and the sound produced has a certain pitch which is characteristic for each species in the family to which the Carolina locust belongs. If there is an unfertilized female near, she comes to the male and he pokes a little packet of sperm into her seminal receptacle with his cerci. She is now prepared to lay fertile eggs. The red-legged locust does not make such a splendid display as its larger relative, just described. However, it sits in the grass and sings a feeble song which is easily recognized by females of its own species.

The bright "recognition" colors, the sound-producing organs, and ears, are of little or no value in procuring food or for self-protection, but are adaptations for mating! So grasshoppers use many means to insure fertile eggs, and the continuance of the race.

After a female grasshopper has been "fertilized" the sperm cells move to the eggs and enter them, the egg and sperm nuclei fusing in the cytoplasm of the egg cell. Thus a single cell is formed by the union of the egg and sperm cells. This new cell is the *zygote*. It has all the characteristics of youth, as described in Chapter III, and is the beginning of a new individual.

Soon after the zygote has been formed it begins to segment, or undergo mitotic cell division (Fig. 25). First the nucleus divides several times and the new nuclei arrange themselves near the outside of the egg; the cytoplasm about each nucleus becomes separate from the rest and a number of little cells are thus formed just beneath the egg-shell (Fig. 44, A, B, C). Development takes place on the outside of the egg because the yolk, or food material fills the interior. As the cells continue to multiply a little *embryo* is soon formed on one side of the "egg" (D), and this later is enveloped by two protective membranes which are known as the *amnion* and *serosa* (E, F). Finally the yolk is all

FIG. 44.—Development of a grasshopper's egg; *A*, an unsegmented egg containing a single nucleus near the center; *B*, an egg in which the original nucleus has divided many times and the daughter nuclei are arranged around the outside of the egg; *C*, a later stage in which the yolk material is completely enclosed by cells; *D*, the thickening on one side indicates the beginning of an embryo; *E*, embryo partly overgrown by amnion; *E'*, cross section of same; *F*, amnion and serosa completely covering embryo; *F'*, cross section of same; *G*, insect with appendages forming.

used up and the young grasshopper is ready to hatch (G).

Soon after fertilization the female grasshopper drills a hole in the ground with her abdomen and deposits thirty or forty eggs, which remain covered until spring. Most of the development within the egg-shell therefore takes place after the eggs are laid. In spring, when the ground is warm enough, the egg-shells break and little wingless nymphs work their way to the surface. The young grasshoppers begin to feed at once, but cannot grow on account of their hard exoskeletons. This difficulty is overcome by a periodical casting of the outer skin (Fig. 45). After such a moult a grasshopper is soft for a short time and grows

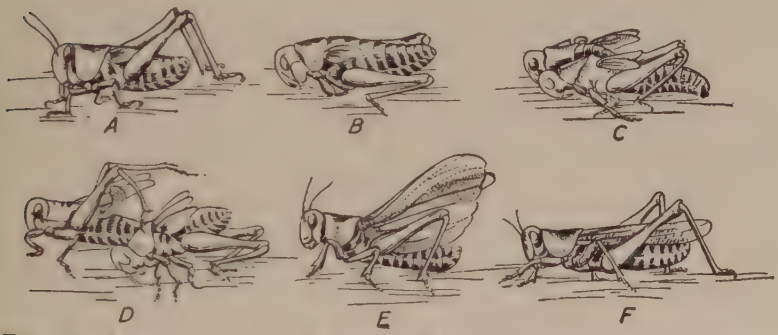


FIG. 45.—A grasshopper nymph shedding its skin. (*After Packard.*) In *E* the adult which emerged is drying its wings; in *F*, it is ready to fly away.

very rapidly. Then the exoskeleton hardens again and there can be no more growth until the next moult. After the first moult a tiny pair of wings appear. These increase in size each time the skin is shed, but do not become functional until the last moult, when complete maturity is attained. After becoming mature the grasshopper seeks a mate, starts off a new generation, and dies. Thus the cycle goes round. The grasshopper must strain every faculty to keep up its race. Its arduous struggle has but one end—to produce offspring and die.

But is this all? The characteristics of animals are handed down with great fidelity generation after generation. Heredity is jealous of any change. But as the ages

go by a race improves a little from time to time, if it struggles. This is an unvarying biological law—struggle and trying bring improvement; lack of struggling and trying bring retrogression and degeneracy. Has the grasshopper improved? If we compare a mature grasshopper with its remote ancestors (Figs. 27, 28) there is no gainsaying that it has gone ahead. It has lost the awkward arrangement of legs on each segment of the body and condensed them on the three thoracic segments so that it can turn quickly and easily. The legs are specialized for certain purposes; wings have developed, improvements have been made in methods of breathing, eating, etc.

Now, how much has our grasshopper attained? How much ability does it display in adjusting itself to its surroundings? Its *structure* is highly specialized and admirably adjusted to the life it lives, but its *mind* is of rather low order. Most of its activities are reflexes or tropisms—*i.e.*, they are repeated each time an individual is subjected to the same set of external conditions. A grasshopper eats when it is hungry, rests when satiated, breeds when ripe, and carries on many other routine activities—but does it reason? We must answer, no, for the most part. A grasshopper can make simple adjustments in its behavior to adapt itself to minor changes in its environment, but its reactions are usually stereotyped. If you put one in a tumbler, it bumps its head over and over again in efforts to escape and there is no "intelligent" effort to seek an exit. Yet, notwithstanding the grasshopper's present lowly mental state, we do not know what it may attain in the future.

CHAPTER IX

PHYLUM ARTHROPODA, CLASS INSECTA
(Continued)

Order 11. **Hemiptera.**—This order includes the "bugs" proper, and no other insects should be called by that name. Bugs are heterometabolous, have sucking mouth parts, and may possess two pair of wings or be without any. There are three suborders:

Suborder 1. **Parasita.**—This group comprises the lice, which are wingless and parasitic. Lice do a small amount

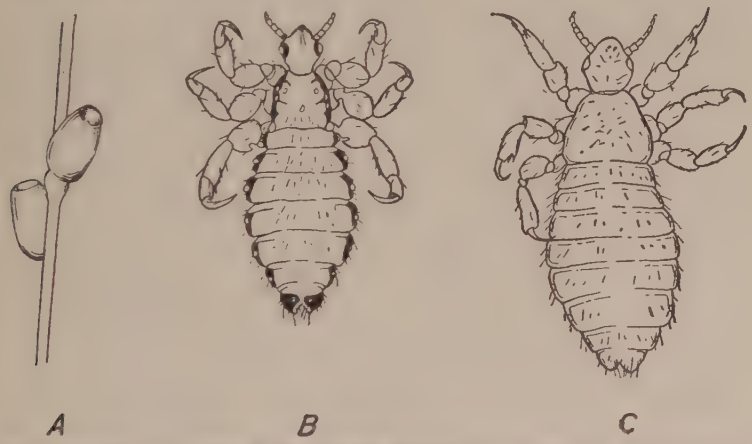


FIG. 46.—Lice. *A*, eggs of head louse attached to a hair; *B*, head louse; *C*, body louse.

of damage by making punctures and sucking blood; but are dreaded chiefly because they may inoculate man with the germs of certain diseases when they pierce the skin. In most parts of the world there are three species which attack man and many more which prey upon other animals.

Pediculus humanus is the head louse (Fig. 46). It is found the world over and its color varies somewhat accord-

ing to the race upon which it is found. It is very common in many tropical countries where the natives may often be seen searching through each others heads for the parasites. The female head louse lays about fifty eggs, attached to hairs. *Pediculus corporis*, the body louse, is larger than the head louse. It is gray in color and hence is known in some localities as the "gray-back." This louse causes much irritation, crawling over the body and inflicting painful bites. The eggs are laid in the seams of garments. The young lice or the adults may be active in discarded clothing. The crab-louse, *Phthirius inguinalis*, is found among the hairs of the pubic region, eyelashes, eyebrows, and sometimes on other parts of the body where it causes irritation, eruption, and discoloration of the skin. It attaches its eggs to hairs.

Though fleas are the chief carriers of the bubonic plague, lice may transmit the disease and have also been suspected of carrying leprosy. Lice are of chief interest, however, as the proven carriers of typhus, a fatal febrile infection of unknown cause. Body lice of course thrive most when people are filthy. The terrible outbreaks of typhus fever in Mexico and Serbia, following the advent of war, were due to poverty and uncleanliness among a rather ignorant population. The chief means used in fighting these great epidemics were simple sanitary measures which would kill or prevent the breeding of lice—*i.e.*, boiling clothes regularly, fumigation of public conveyances, and the use of blue ointment, paraffin oil, or kerosene on the surface of the body.

Suborder 2. **Homoptera** (Fig. 47).—Hemipterous insects with four similar membranous wings; the mouth parts form a jointed beak which arises from posterior ventral part of the head. Many insects of great economic importance belong here—scale insects, plant lice, cicadas, tree-hoppers, spittle insects, etc. All these obtain their food by burying their beaks in plants and sucking the sap. The three following families are of particular importance:

Aphidæ, plant lice or aphids. These little insects are

all of small size, and often occur in great numbers on plants. In spring and during the summer certain females, the "stem mothers," bring forth living young which have developed from unfertilized eggs. In the autumn male individuals appear, and fertilized eggs are laid which pass through the winter. Several different kinds of individuals

Fig. 47.—Homoptera. At the left are plant-lice, or aphids, one being devoured by a lady-bird beetle (not Homoptera); above are leaf-hoppers and "brownie bugs," or tree-hoppers; on the tree trunk is a cicada, or seventeen-year locust, which has just emerged from its nymphal skin, and two species of scale insects.

are often present in the same species: winged, wingless, woolly, smooth, large, small, etc. The grape-phylloxera is a destructive species which perforates the roots of plants and starts diseases; green-fly on wheat, and the woolly apple aphis are also important.

Coccidæ, scale insects. These are particularly destruc-

tive to trees and fruit. They are always of minute size but may be very abundant. The male is winged and moves about freely. The female buries her beak in a plant when young and never moves again. She has no wings, and her body is covered by a secreted "scale." She lays eggs which hatch beneath the scale. The young females settle down near their mother, hence scale insects spread rather slowly. The most important species economically are the San Jose scale, introduced originally into California but now found in most parts of the United States, the cottony cushion scale, and the oyster scale.

Cicadidæ, the cicadas. The seventeen-year "locust" is the best known representative of this family. The adults sing discordant notes in trees during late summer and, after mating, lay eggs in the twigs of trees. The larvæ hatch in about six weeks, drop to the ground, and live underground for nearly seventeen years as ugly nymphs. The nymph burrows about in the soil, feeding on roots and humus. In the summer of the seventeenth year it crawls out of the earth, climbs upon some plant, and an adult cicada emerges from its skin (Fig. 47).

Other insects belonging to this suborder are the tree-hoppers, leaf-hoppers, lantern-flies, white-flies, spittle insects, etc. The tree-hoppers and leaf-hoppers have peculiar triangular or pointed heads. The spittle insects are found within a mass of froth on low vegetation.

Suborder 3. **Heteroptera,** the True Bugs (Fig. 48).—In this order the fore and hind wings differ; the former being thick in front and thin behind; the latter, entirely membranous. The peculiar fore-wings give the name (Hemiptera—half wings) to this whole order of insects, though they are of course not characteristic of the first two suborders. Several insects of great economic importance belong to this group, and many are common "water-bugs."

Among the aquatic Heteroptera are many with interesting habits. All breathe air and must therefore have special

means for respiration. Corixa is the water-boatman which has the hind legs flattened to form two great oars. When swimming under water it carries air between the fine hairs which cover the body and beneath the wings, hence is able to stay submerged for a long time. Notonecta, the back-swimmer, is something like Corixa, but usually swims with its ventral surface up. The water-scorpions (Nepa, Ranatra) have long slender breathing tubes for taking air from the surface of the water; Nepa is flat, Ranatra is long and slender. Belostoma is the giant water-bug or "electric light" bug, which often flies over the land at night. Its small relative, Zaitha,

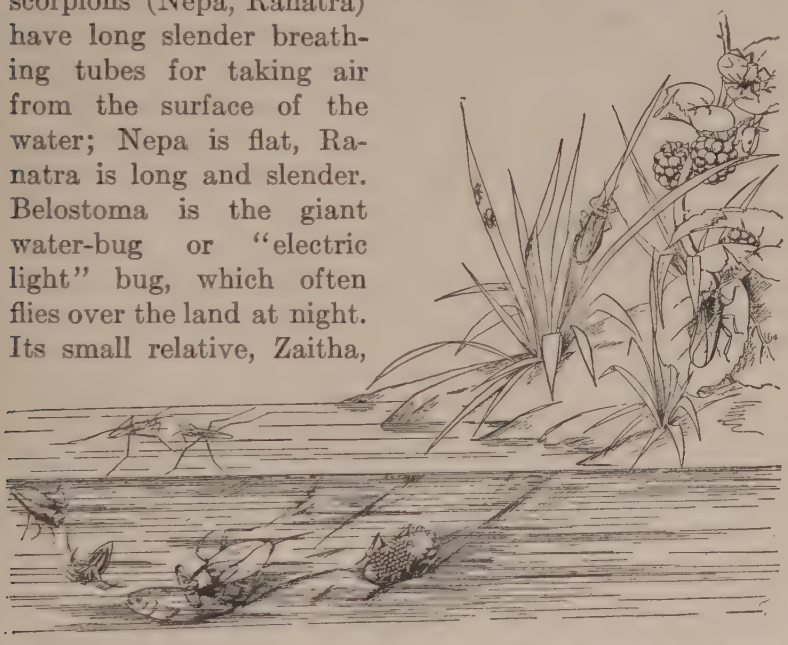


Fig. 48.—Heteroptera. From left to right the insects are the water-boatman (*Corixa*); back-swimmer (*Notonecta*); water-striders (*Gerris*); a water-scorpion (*Nepa*) catching a minnow; a male water-bug (*Zaitha*) carrying eggs on his back; chinch-bugs; flower-bug; assassin-bug; squash-bug.

is of interest on account of its peculiar breeding habits. The female sticks her eggs on the back of a male, and he is obliged to carry them around till they hatch. The marsh-treaders and water-striders (Gerris, etc.) run over the surface of the water with great skill. They are kept from sinking through the surface film by the little hairs on the legs which cannot be wet. All the aquatic bugs are

predaceous, feeding on insects, worms, small fish, and tadpoles.

The terrestrial bugs in this suborder are common everywhere. The flower-bugs are small in size but often very numerous on plants, where they lurk to catch minute insects. The large assassin-bugs feed mostly on insects. They pierce them with their strong beaks and suck the juices. Some species, such as the one most often known as a "kissing-bug," *Reduvius personatus*, are able to inflict painful bites on man. The ambush bugs are colored like flowers, and this enables them to capture small insects which come to the blossoms they frequent. There are over 250 species of leaf bugs (*Capsidæ*) in the United States, and many are garden pests, though some are predaceous. The squash-bug, *Anasa tristis*, is well hated by every gardener, being a persistent enemy of squashes. The chinch-bug, *Blissus leucopterus*, occurs throughout the United States and in parts of Canada. It is particularly abundant in dry seasons. The annual loss in the United States due to this insect has been estimated at $20,000,000. The stink-bugs are easily recognized by their characteristic odor. Some species feed on plants, others on insects.

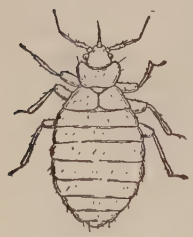


Fig. 49.—The bed-bug.

The bed-bug, *Cimex lectularius* (Fig. 49) is parasitic and has the wings represented by very small scales. It lays its eggs in cracks, nail holes, mattresses, under wall paper, and in other suitable places. It is entirely nocturnal, feeding while its victims slumber. Killing a bed-bug by hand is no easy matter. The body is so flat that it can stand considerable pressure without being injured. In India and certain other warm countries the bed-bug carries an important human disease known as kala-azar.

Order 12. **Neuroptera** (Fig. 50).—This is a small order which, however, contains some very interesting insects. All have four membranous wings with many "veins,"

biting mouth parts, and a complete metamorphosis (holometabolous). The ant-lions are the larvæ of a neuropterous insect, *Myrmelion*. They live in little burrows which open at the bottom of conical pits. When a small insect starts to slide down the side of the pit, they throw sand at it. The victim finally reaches the formidable jaws waiting at the bottom of the pit. The aphis-lion hatches

FIG. 50.—Neuroptera. At the left is the lace wing with its eggs and nymph (aphis-lion); in the center the ant-lion and the insect which emerges from it are shown; at the right is the dobson-fly and its larva.

from curious little stalked eggs, and spends its larval life searching over plants for aphids, which constitute its chief food. It thus does much good to man. The adult of the aphis-lion is the beautiful little lace-winged fly, *Chrysopha*. The dobson-fly, or hellgrammite, *Corydalis cornuta*, is a large insect (four inches across with spread wings) with

vicious-looking jaws. The larva is known by many names (dobson, crawler, amly, conniption bug, clipper, water grampus, goggle goy, bogart, helldevil, flip-flop, etc.), and is often used by fishermen for bait. It is an inch or more in length, has three pairs of legs and a fringe of slender gills along either side of the abdomen.

Order 13. **Mecoptera.**—The scorpion-flies possess wings similar to the Neuroptera; the head is prolonged ventrally into a long beak which has biting jaws at its tip; metamorphosis is holometabolous. The common name refers to the structure present in some species at the end of the male abdomen which somewhat resembles the sting of a scorpion.

Order 14. **Trichoptera,** Caddis-flies (Fig. 38).—The larvæ of the insects in this order are the caddis-"worms" which make little tubes or cases to protect the body. The tubes are usually carried about with the larvæ, but are sometimes fastened to rocks or stones. They are characteristic for each species, in regard to both materials and architecture. Some species make their cases entirely of snail shells, others use sticks, leaves, sand, etc. Adult caddis-flies have four membranous wings, covered with little hairs. They live only a short time (long enough to mate and lay eggs) but often occur in great numbers near bodies of water where they passed their larval life. The mouth parts of caddis-flies are rudimentary, as in may-flies.

Order 15. **Lepidoptera** (Fig. 51).—Here belong the butterflies, skippers, and moths. These insects have four wings covered with scales; the mouth parts form a long sucking tube; all are holometabolous.

The larvæ of lepidopterous insects are caterpillars, which often do damage by gnawing vegetation. The adults feed largely on nectar, sucked out of flowers by means of the long proboscis. When not in use the proboscis is coiled up beneath the head. There are over 7000 species of Lepidoptera in the United States, and many are of great economic importance. This vast array is divided into two sub-orders:

Suborder 1. **Rhopalocera,** butterflies and skippers, in which there is a knob or swelling at the tip of each antenna. Skippers have also, in addition to the knob, a terminal recurved point.

Fig. 51.—Lepidoptera. At the left a cecropia moth with its eggs, larva, and cocoon; at the right a monarch butterfly with eggs, larva, and chrysalis.

Suborder 2. **Heterocera,** moths, which have no knobs at the ends of the antennæ.

The colors of butterflies and moths are often very beauti-

ful. They are produced by the little scales which cover the wings and other parts of the body. They may be due to the presence of specific pigments which give a particular tint to the surface, or they may be "refraction colors" caused by the spreading of the light from the many small flat surfaces presented by the scales. Reds, yellows, and browns are usually pigment colors, while greens and blues are more often due to refraction.

The development of lepidopterous insects (Fig. 51) may well illustrate the holometabolous type; the monarch butterfly and cecropia moth serving as examples. The monarch lays its eggs in little groups on the underside of milkweed leaves. These eggs produce minute larvæ which at once begin to feed on the leaf where they hatch. The larvæ grow rapidly, moulting several times, and when mature measure an inch or more in length. They then attach themselves in a suitable place, moult the larval skins, and become naked pupæ, or chrysalids, which hang suspended until they in turn moult to become imagoes, or adult butterflies. The cecropia moth lays its eggs in the spring on willows, and the larvæ which hatch feed voraciously on the leaves. When grown each of them spins a cocoon about itself and passes through the winter attached to some branch, safe inside its silken covering. In the spring an adult moth emerges from the pupal skin and forces its way out of the cocoon. The imago of this moth never eats and its mouth parts are rudimentary. Its chief work in life is to find a mate and start a new generation.

There are many butterflies of particular interest. Among the most beautiful are the swallowtails (Family *Papilionidæ*) which have slender appendages from the posterior portion of the wings. The mourning-cloak butterfly (*Euvanessa antiopa*) is one of the harbingers of spring in most parts of the United States. Its larva often does damage to poplar and willow trees. The "monarch" (*Anosia plexippus*) and "viceroy" (*Basilarchia archippus*) furnish an excellent case of mimicry. The monarch is dis-

tasteful to birds; its red color gives notice of its undesirability, and it generally is let alone. The viceroy lives on the monarch's "reputation." It is apparently of good flavor, for it is readily eaten by birds if its color is rubbed off. Its color and general appearance, however, are very much like those of the monarch, and it is consequently avoided by predaceous animals. Probably the commonest butterfly in the United States is the cabbage butterfly, *Pieris rapæ*, which is white with black spots on its wings. Its larva is the green caterpillar which is often so destructive to cabbages.

Moths are of much more economic importance than butterflies. Many species do injury and some are highly beneficial. Among destructive larvæ may be mentioned: the webworm, on trees and shrubs, tent caterpillars (trees), cotton worm, tobacco worm, army worm (garden crops), boll worm (cotton), canker worm (fruit trees), codling worm (apple), and the larvæ of the gypsy (trees), tussock (trees), clothes, flour, and grain moths. The larvæ of the brown-tailed moth has lately attracted considerable attention in the Eastern United States. A person who accidentally touches one of the caterpillars may have poisonous hairs imbedded in the skin, and a festering eruption results.

The silkworm, *Bombyx mori*, stands preëminent among beneficial insects. This larva is fed on mulberry leaves and after attaining its growth spins the cocoon in which it becomes a pupa. This cocoon is the only source of commercial silk. The silk industry originated in China but the propagation of silk worms is now carried on in most parts of the world where conditions are suitable. To obtain silk, the cocoons are plunged into hot water and unwound, thus unraveling the fine threads which originated in the spinning glands of the silk moth larva. Silk industries in the United States amount to about $100,000,000 a year.

CHAPTER X

PHYLUM ARTHROPODA, CLASS INSECTA
(Continued)

Order 16. **Diptera,** Flies.—This great order includes the insects with two wings (the flies, mosquitoes, gnats, etc.) and a few degenerate species which have no wings. The hind wings are usually represented by a pair of halteres, or poisers, the mouth parts are fitted for sucking or piercing, and the metamorphosis is complete. More than forty thousand species of Diptera have been described and probably 300,000 more are as yet unknown. Howard says: "Not only have the true flies a superiority in point of numbers, but entomologists are concluding that they probably stand at the head of the insect system in point of evolution, that is to say, they are the most specialized of insects." They are also of great importance as disease carriers. There are two suborders:

Suborder 1. Diptera genuina; true flies.
- Section 1. Nematocera (Fig. 52); long-horned flies: mosquitoes, crane flies, gall-gnats, midges, black-flies.
- Section 2. Brachycera (Fig. 53); short-horned flies: horse-flies, bee-flies, robber-flies, house-flies, bot-flies, flower-flies.

Suborder 2. Pupipara; "ticks" and sucking lice. All parasitic.

Crane flies (*Tipulidæ*) look like big mosquitoes. They are commonly seen in late summer in pastures and woods. The larvæ of most species live in the earth but some exist in water, in rotten wood, or even upon the leaves of plants.

The mosquitoes (*Culicidæ*) are of particular interest to man. They not only cause inconvenience and irritation by their bites, but also carry some of the most important of human diseases. The eggs of most mosquitoes are laid on water (Fig. 52). They hatch into little "wigglers,"

which after about a week are in turn transformed into awkward pupæ. Though the larva and pupa live in water, they breathe air and must therefore come to the surface from time to time. The adult mosquito lives a longer or shorter time, depending on the amount of food it is able to secure and how soon it finds a mate. Some species are able, under favorable conditions, to pass through their entire life cycle in a week (egg, one day; larva, four; pupa, two; adult,

Fig. 52.—Diptera, Nematocera. Crane fly and larva; mosquito with eggs, larva, and pupa; willow-cone gall fly; midges with larva and pupa.

variable). Mosquitoes are very prolific breeders; it is possible for one pair to produce two hundred million in four months. An adult mosquito may live for five months, perhaps longer. It is thus able to exist long after breeding ponds have dried up, and can hibernate during the winter. Male mosquitoes do not suck blood. They usually subsist on plant juices, and will sip water, wine, etc.

A female may also eat plant juices, but requires a meal of blood before she can ripen her eggs.

Among important mosquito-borne diseases are malaria, yellow fever, filaria, and dengue fever. Malaria is caused by parasitic animals (*Plasmodium*) which live in the red blood corpuscles of man and in mosquitoes. It will be considered in detail in Chapter XII; it suffices to say here that it is carried only by mosquitoes of the family *Anophelinæ*. Man can get malarial fever only through the bite of such a mosquito. The genus *Stegomyia* is the sole carrier of yellow fever. Filaria is a parasitc worm (page 187), causing the horrible disease known as elephantiasis, in which parts of the body become enormously enlarged. This malady is also inoculated hypodermically into the bodies of unsuspecting persons by certain mosquitoes while sucking the blood. The commonest mosquito in the United States, *Culex*, carries bird malaria but does not transmit any human diseases.

The best way to treat mosquito-borne diseases is by preventive measures—*i.e.*, better not to have the disease than to try to get well after it has been acquired. This means fighting mosquitoes, and in warm countries where such diseases are prevalent, every intelligently managed economic project has a staff of men who devote their whole time to general sanitation. The building of the Panama Canal depended as much upon the efficient work of doctors and zoologists as it did upon the efforts of engineers, steam shovels, and laborers. Mosquito larvæ are eliminated from particular districts by putting oil on the water; by introducing natural enemies of the larvæ, such as sticklebacks, top-minnows, and other fish; and by the elimination of breeding places (filling in or draining swamps, covering reservoirs, etc.). The adults are kept from houses by fumigation, screening, locally applied "dopes," etc.

The midges (*Chironomidæ*) are of great economic importance, chiefly because they occur in such numbers as to furnish an easily obtained food for many animals. The

larvæ are aquatic and some are known as "blood-worms" on account of their color. Fishes commonly feed on them and on midge pupæ. Many birds, insects, and spiders eat the adult midges, which often occur in great swarms, covering trees, buildings, and everything else over large areas. Such swarms are more apt to come in the spring than at other seasons of the year. Though some of the midges resemble mosquitoes in general appearance, most species are perfectly harmless. The larvæ live mostly on aquatic vegetation and the adults usually do not suck blood. The minute "punkie" or "no-see-um," of the northern woods is an exception, as those who have been punctured by these minute pests can testify.

The gall-gnats (*Cecidomyiidæ*) resemble mosquitoes in appearance but do not bite. Their larvæ differ considerably in their habits, but those of most species form galls on the twigs or leaves of plants. The most notable species of the family is the Hessian fly, *Cecidomyia destructor;* which does many millions of dollars worth of damage annually to the wheat crop of the United States. Another common species forms curious galls on willows, which resemble pine cones in shape (Fig. 52). Others live on the golden rod, sunflower, aster, and other plants. The little black-flies, sand flies, or buffalo-gnats (*Simuliidæ*) are stout, hump-backed Diptera which are great pests in many parts of the world. Their larvæ live in swift flowing streams. The adults are extremely blood-thirsty; cases are known in which cattle, and once even a man, were killed by the bites of these little insects.

Among the short-horned flies (Brachycera, Fig. 53) the horse-flies (*Tabanidæ*) may first be considered. These insects are also known as gad-flies, deer-flies, breeze-flies, etc. They are active, strong-flying creatures. The females live by sucking blood from warm-blooded animals, but the males are harmless and get their sustenance from plant juices. Tabanids usually lay their eggs above water on cat-tails, rushes, and other aquatic plants. The larvæ are

carnivorous and live either in or near the water. The bee-flies (*Bombyliidæ*) superficially resemble bees, having spotted or banded wings and hairy bodies. They frequent flowers and their long proboscis enables them to get nectar and pollen. Their larvæ are often parasitic on noxious insects, such as caterpillars and grasshoppers, and hence are beneficial to man. The robber-flies (Asilidæ, Fig. 53) are veritable hawks among insects. They are slender-bodied creatures which fly with great agility, often capturing insects larger than themselves on the wing. Though

Fig. 53.—Diptera, Bracycera. Flower-fly, drone-fly and its "rat-tail" larvæ, robber-fly, flesh-flies and maggots on fish, horse fly with larva and eggs.

generally beneficial, they sometimes do injury to bee-keepers and are known in some parts of the country as "bee-killers." The bot-flies (*Œstridæ*) are parasitic and have unique habits. The larvæ live in the bodies of living animals; the common one in the horse being found in the stomach; those of man, the cow, and rabbit beneath the skin. The tachina flies (*Tachinidæ*) do much good by destroying caterpillars and other insects. They lay their

eggs in the bodies of their hosts and the larvæ live as internal parasites. The flesh-flies or blow-flies (*Sarcophagidæ*) are commonly found about decaying meat. The maggots burrowing through their food; the adults eat and lay eggs on the outside. The larvæ are sometimes found in living animals, including man. The flower-flies (*Syr-*

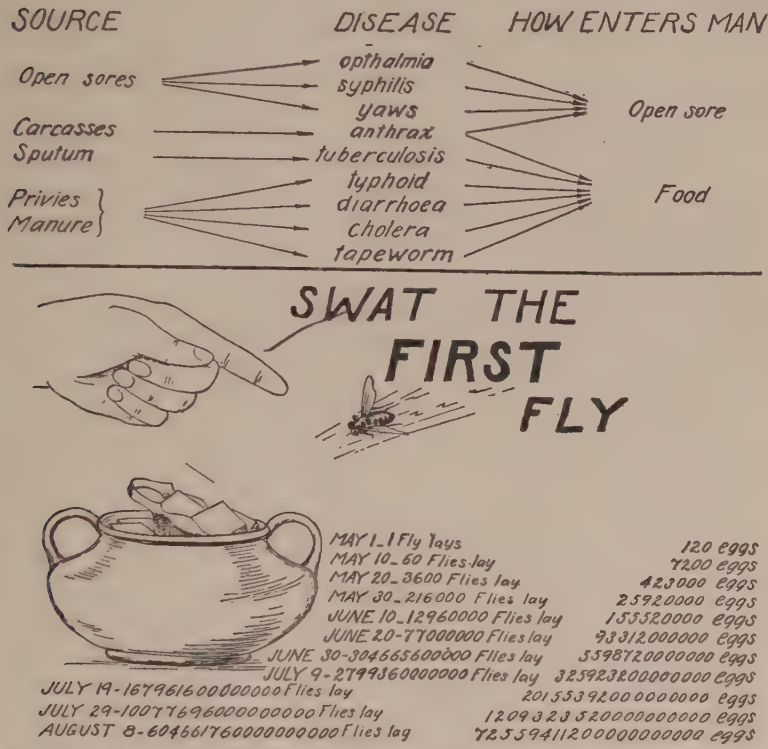


Fig. 54.—Showing the relations of flies to disease and a cartoon from a current newspaper.

phidæ) frequently are abundant in the United States. They fly about on bright days and rest at other times in flowers or among leaves. Their food varies greatly in the larval state, but as adults most species subsist on pollen and nectar.

The house-flies (*Muscidæ*, Fig. 54) are probably of more

importance to man than any other group of insects. The commonest species are the house-fly, *Musca domestica*, and the stable-fly, *Stomoxys calcitrans*. The horn-fly of cattle, *Hæmatobia serrata*, is also well known to farmers. Many flies belonging to this family are of value as scavengers, destroying decaying matter through their great numbers and rapid breeding. The horn-fly and stable-fly produce great losses in the dairy and stock industries by their attacks on cattle. The common house-fly, and its near relatives, do untold injury to man. The facility with which these insects take to civilized life and their uncleanly habits make them ideal carriers of disease germs. The house-fly commonly breeds in the excreta of diseased men or other animals, and its roving habits make it a continual source of contamination. Many bacteria will pass through its alimentary canal without losing their virulence. Thus a house-fly not only goes about with dirty body fouling everything it touches, but is continually defecating and spitting out germ cultures as it goes. Typhoid fever, diarrhœa, and cholera are commonly carried by house-flies. Tuberculosis, infantile paralysis, anthrax, and yaws may spread in the same way. Perhaps syphilis, eye diseases, leprosy, diphtheria, small pox, plague, and tropical sores may also be carried by flies in some cases (Fig. 54). Small wonder that the house-fly is the most dreaded hanger-on of civilization and that many communities have taken active measures to keep it down.

Order 17. **Siphonaptera,** Fleas (Fig. 55).—These insects show many adaptations to parasitic life on mammals. They are greatly compressed, so that they are not easily squeezed to death and may easily ramble about among hairs. The mouth parts are suitable for sucking blood. There are no wings, but the powers of jumping are remarkably developed. A flea is thus able, if it drops off one animal, to hop on another when it comes near. Fleas lay their eggs in cracks in floors and similar situations. The larvæ eat sweepings, or almost any sort of waste

material, such as may accumulate about the abodes of animals. Adult fleas feed on various warm-blooded animals. Dogs, cats, rats, men and other animals have characteristic species associated with them. Most species of fleas prefer a particular host, but will feed on others if hungry.

Fleas have lately excited interest among medical men because they have been found to be carriers of several diseases. The rat flea, *Xenophylla cheops*, carries the bubonic plague. This dreadful disease has several times become established on the borders of the United States, being introduced on vessels from foreign countries. Preventative measures consist in the destruction of rats and

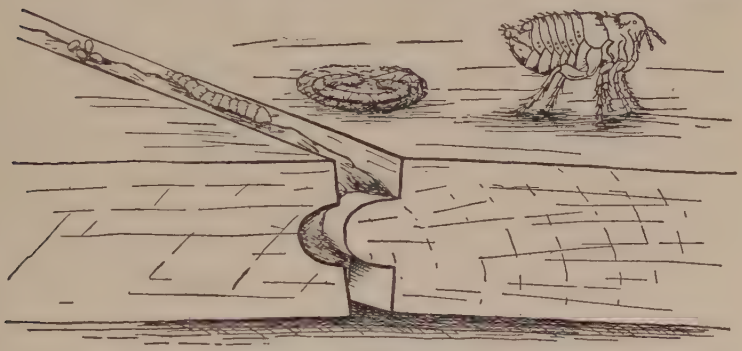


Fig. 55.—A flea with its eggs, larva, and cocoon.

other rodents, placing metal "rat guards" on the cables of ships while in port, fumigation, etc. Where the plague has become established, regular campaigns must be waged. In California the government has recently hired squads of men to destroy rats and ground squirrels. In New Orleans the houses in certain parts of the city were completely destroyed and replaced by "rat-proof" buildings.

Order 18. **Coleoptera,** Beetles (Fig. 56).—This order contains an enormous number of species. There are about twleve thousand in the United States. Beetles have two pairs of wings, the first pair forming hard sheaths, or elytra, which cover the membranous hind wings. Their

mouth parts are fitted for biting, and metamorphosis is complete. There are eight suborders:

Suborder 1. **Adephaga.**—The beetles in this group are all carnivorous. Two important families live on land and the other two are aquatic. The tiger-beetles (*Cincindelidæ*) are bright-colored active creatures which seek their prey

Fig. 56.—Coleoptera. June-beetles, their grub and pupa; potato-beetle; lady-bird; rove-beetle; tumble "bug"; plant slugs; click-beetle; predaceous ground-beetles; snout-beetles; weevils.

in open places, such as roadways and sandy beaches. The predaceous ground-beetles (*Carabidæ*) are usually black or brown. They search the surface of the soil for caterpillars and other small insects which they attack with great vigor. The predaceous diving-beetles (*Dytiscidæ*) are found among aquatic vegetation where they catch various small animals. The whirligig-beetles (*Gyrinidæ*) make curious gyrating movements on the surface of the

ponds or rivers. Their food consists mostly of small insects which fall into the water.

Suborder 2. **Clavicornia.**—The club-horned beetles have the antennæ swollen at the distal ends. Their habits vary greatly. The water-scavengers (*Hydrophilidæ*), rove-beetles (*Staphylindæ*), and burying-beetles (*Silphidæ*) do great good by disposing of dead animals. The grain beetles (*Cucujidæ*) are injurious in granaries. The larder-beetles (*Dermestidæ*) are great pests in museums, factories, etc. They eat all sorts of organic substances, but are particularly fond of dry animal remains, such as insects and furs.

Suborder 3. **Serricornia.**—The saw-horned beetles have serrated antennæ. Here belong the metallic wood borers (*Bupestridæ*) which injure trees and logs; the click-beetles (*Elateridæ*), so-called because they can flip themselves over when turned on their backs; the fireflies and soldier-beetles (*Lampyridæ*); and others.

Suborder 4. **Lamellicornia.**—The blade-horned beetles have the distal ends of their antennæ flattened. The stag-beetles (*Lucanidæ*) are probably beneficial, as they destroy other insects. Their name refers to the peculiar antler-like growths on the heads of the males of some species. The family *Scarabæidæ* contains a number of beetles which fall into two groups as regards habits. The scavenger-beetles eat decaying matter. The tumble-bug is an example. It places its eggs in a ball of manure, which it rolls to some hole and buries. The Sacred Scarabæus of Egypt belongs in this family. The leaf-chafers are injurious vegetarians; the common June-bug, *Lachnosterna fusca*, being an example. This beetle is a biennial. It spends over a year in the ground as a white grub, and hence is abundant only every third year.

Suborder 5. **Phytophaga.**—The plant-eating beetles include the long-horned wood-borers (*Cerambycidæ*) and the bean weevils (*Bruchidæ*). The larvæ of these insects are able to bore their way through very resistant materials.

The most important family is the *Chrysomelidæ* which contains most of the common beetle pests—the potato-bug, elm-leaf beetle, cucumber-beetle, etc.

Suborder 6. **Trimera.**—This order contains only one important family, the *Coccinellidæ*, or lady-bird beetles. These little insects both as larvæ and adults, do great good to man by feeding on aphids and scale-insects.

Suborder 7. **Heteromera.**—The darkling and blister-beetles are of considerable economic importance. The former (*Tenebrionidæ*) include *Tenebrio molitor*, the larva of which is the "meal-worm" so common about flour and grain bins. One of the blister-beetles (*Meloidæ*) when dried and pulverized, has the peculiar property of raising blisters on the human skin, and is used by physicians for that purpose.

Suborder 8. **Rhynchophora.**—The snout-beetles differ from all others in having the head prolonged into a beak, with tiny mouth parts at its tip. The bark-beetles (*Scolytidæ*) are most injurious of all insects to forest trees, causing $100,000,000 worth of damage annually in the United States. The larvæ make tunnels beneath the bark of living or dead trees and thus open the way for rot- and decay-fungi. The curculios and weevils damage fruits and grains.

Order 19. **Hymenoptera** (Fig. 57).—To this order belong the gall-flies, ichneumon-flies, horn-tails, saw-flies, wasps, bees, and ants. These insects possess four membranous wings with few veins; their mouth parts are fitted for both biting and sucking; the female often has a long ovipositor so modified as to form a sting; the metamorphosis is complete. Many of these are of unusual importance to man. There are about 7500 species in North America. Only the most important families can be mentioned.

The saw-flies (*Tenthredinidæ*) are so named on account of the saw-like ovipositor possessed by the females. The adults are rather inconspicuous, but many of the larvæ are well known as rose-, currant-, pear-, larch-, and willow-

slugs. The horn-tails (*Siricidæ*) are related to the saw-flies. The females have a long hard ovipositor at the end of the abdomen with which they drill holes in trees. The larvæ burrow in the heart wood and grow into white grubs.

The gall-flies (*Cynipidæ*) lay eggs in living buds, leaves, or stems, and their larvæ develop inside galls which develop on the plants attacked. Though such abnormal growths are found on many plants they are most common on the

Fig. 57.—Hymenoptera. Chalcid-fly and cocoons on caterpillar; bees and wasps; ichneumon-flies; horn-tail larva.

oak, rose, and hickory. All the gall-flies are of small size, the largest being only a third of an inch long. The galls produced by different species are quite characteristic. They present a great variety of forms—rosettes, stars, spheres, and other shapes. The growth of a gall is due to the irritation from the developing larva within. Some gall-flies do not form galls of their own, but lay their eggs in the growths produced by other species.

The chalcid-flies (*Chalcididæ*) do great good to man by laying their eggs in insects, particularly caterpillars. The eggs hatch in or on the host and the larvæ burrow about among the internal organs. Sometimes in the summer one may find a dead caterpillar covered with little white cocoons. These contain the pupæ of chalcids which lived within the caterpillar as larvæ.

The ichneumon-flies (*Ichneumonidæ*) are also parasitic on caterpillars and other insects. There are many species and most of them attack only one host. *Thalessa lunator* (Fig. 57) is an interesting parasite on the larvæ of the pigeon horn-tail, *Tremex columba*. These larvæ are found in the heart wood of trees. The female Thalessa bores into a tree with her slender ovipositor and lays her eggs in them.

There are several families of wasps. The most primitive species are diggers, carpenters, or masons. Some tunnel in the ground, others make galleries in wood, or plaster pellets of mud together to form nests. Such cavities are stored with spiders, caterpillars, and other insects. An egg is deposited with accumulated food and each cavity is sealed up. The sting of a wasp contains a poison which paralyzes the nervous system of its prey. The insects placed in the cells with the eggs are not killed, but only paralyzed. They thus remain in "cold storage" until the wasp's larva is ready to devour them. The social wasps (*Vespidæ*) live in colonies. They do not seal up the egg with stored food, but care for and feed the larva soon after it hatches. The greater part of each colony dies when winter comes. Single fertile females hibernate in rotten stumps, in barns, under logs, and in similar situations. In spring each builds a little nest and begins to lay eggs. As soon as the young wasps emerge from the pupal condition they begin to help enlarge the nest, gather food, and care for the young. The original queen, the males, and the "workers" (which are sexually immature females) all die in the autumn. Before the colony breaks up, how-

ever, the males fertilize young females so as to enable them to start colonies for the next year. The two common "paper-wasps" in the United States are Vespa and Polistes. Their nests are made of chewed vegetable fibers.

The bees are included in one great family, *Apidæ*. As among the wasps there are solitary and social species. There are also burrowers, carpenters, leaf-cutters, etc. Bees may have short or long tongues and the food varies accordingly. The bumble bee is like the social wasps, in that most of the colony dies with the advent of winter. The honey-bee, however, has a perennial community which gives off new colonies by "swarming." When swarming takes place a queen rushes from her parent hive, followed by most of the workers and the drones, or males. She is fertilized but once, while making this flight, and is then able to lay thousands of fertile eggs. Scouts go out from the swarm and locate a good place for a new colony. The queen never leaves the new home, but spends her time going about laying eggs in the comb which the workers construct. She is fed and cared for by the workers, but usually dies after three or four years and is replaced by a young queen. The bee-industries in the United States are of considerable importance. About seventeen million dollars worth of honey and wax are produced annually.

The ants (*Formicidæ*, Fig. 58) are remarkable for their development of social instincts. They have gone far ahead of the bees in this respect, and even excel the termites. The queens start the colonies, as among other social Hymenoptera, and the workers are all sterile females. Polymorphism reaches great extremes in all the castes. The queens and males may be large or small, and with or without wings. The worker caste may have several varieties, such as large and small workers, soldiers, doorkeepers, crop harvesters, and nurses.

Ants carry on many complicated activities which involve the coöperation of all members of the colony. The leaf-cutters of tropical America build large nests in forests.

From these the workers, under protection of soldiers, go forth in great armies along beaten paths. They seek out particular plants from which the leaves and stems are methodically snipped off. The booty is carried back to the nest, taken underground, and chewed into fine bits by another caste. The soft finely divided mass is then spread out in underground beds and planted with a peculiar fungus which is the sole food of leaf cutters. The particular species of fungus used by the ants has never been found except in their nests. It is, therefore, as much

Fig. 58.—An ant's nest showing queen, workers, soldiers, eggs, larvæ, pupæ, and beetle guests.

a "tame" or cultivated crop as the cabbages and potatoes of men. When a young queen is ready to start a new colony she takes a little pellet from the fungus bed and places it in a little pocket at the back of her mouth. She then goes to some favorable locality, digs a little burrow in the ground, cuts and chews a few leaves, and makes a little bed. The pellet is taken from her mouth and planted on the bed. All these operations take a month or more and during this time the queen takes no food. She now lays eggs and cares for the larvæ which hatch from them. As

soon as the youngsters mature, however, she does no more work, but is fed and kept clean by them.

The large red mound-building ant, Formica rufa, found in various parts of the United States, commonly enslaves other species. A suitable nest is located in advance and the whole colony raids it—killing the soldiers and carrying away the workers, larvæ and pupæ. Some tropical ants are so dependent upon slaves that they are not even able to feed themselves. The harvesting ants collect certain seeds which they husk, dry, and store in little underground granaries.

The complex communities of ants all center about the queen. She is always guarded, cleaned, and fed with great care. She must be kept in good condition, for the continued existence of the colony depends upon her ability to lay eggs. The males are of no service to the community except to fertilize the queen. The workers carry on all general activities. They gather food and feed each other, fight, dig, gnaw, clean, nurse, etc. The instinct to regurgitate food from the crop to feed other ants is strongly developed and is probably largely responsible for the extreme development of castes among ants. It makes it possible for one caste to do all the food collecting and feeding, while other individuals become specialized for other occupations.

Yet, notwithstanding the complex activities of ants, they have little "intelligence." They follow their instincts slavishly and are not able to solve the simplest problems. Different individuals of a colony recognize each other largely by odor. Experiments have been performed in which strange ants were smeared over with the extract from the bodies of certain individuals from a particular colony. When these disguised individuals were put in the nest from which their odor came, they were received as friends. In another experiment an ant was taken from a nest and its odor was washed off. On being returned to its own nest, it was seized and torn to pieces.

This blind following of reflexes and instincts makes ants much subject to deception by other animals. Such rascals live as social parasites in ant communities and are not ejected—though they do no work—because they have the proper odor or some other quality which takes advantage of the ant's simple instincts. More than fifteen hundred species of ants' guests, or myrmecophiles, are known. These include beetles, isopods, and other arthropods. Many of them are not known to occur except in ant's nests (Fig. 58).

CHAPTER XI

PHYLUM ARTHROPODA, CLASS ARACHNIDA

The arachnids differ from all other arthropods in the following combination of characters: (1) no antennæ; (2) no true jaws, or mandibles; (3) the head and thorax are combined to form a cephalothorax, which bears four pairs of walking legs and is usually distinct from the abdomen. There are twelve orders in the Class Arachnida but only four will be considered. The other eight contain animals which are rare, minute in size, or confined to tropical countries.

ORDER 1. ARANEIDA, SPIDERS

The true spiders (Fig. 59) have two body regions—the cephalothorax and abdomen. The cephalothorax is rectangular and flattened; the abdomen is unsegmented, soft, and rounded. The spiders are, therefore, readily distinguished from the other common arachnids. The ticks and mites have no division of the body into regions; in the scorpions the body is flattened and the abdomen is very slender; and in the phalangids, or "daddy-long-legs," the appendages are slender and the body small.

The class Arachnida received its name on account of the spinning ability of the spiders. It is related in ancient mythology that Arachne was a mighty spinner; so good, in fact, that she became conceited and boasted that she could beat Minerva herself. That great goddess, after spinning and winning a match with the foolish Arachne, turned her into a spider. And thus, says the legend, spiders had their beginning. Modern zoology has kept Arachne's memory green by naming spiders and related arthropods for her,

but only the true spiders are able to spin. In order to give some idea of the daily life of a spider, the activities of the common garden spider will now be considered.

THE GARDEN SPIDER, *Miranda aurantia* Lucas

Self-maintenance.—The golden garden spider (Fig. 59) spreads its beautiful orbs on low shrubs, bushes, or even among tall grasses. These symmetrical webs are traps

FIG. 59.—Spiders. Orb weavers and cocoon; ground spider carrying its cocoon; jumping spider; young individual ready to "balloon"; a tent weaver; a wasp flying to its nest with a spider; crab-spider lurking in a flower.

set to catch prey. Their building and maintenance require a great deal of work. They are made from "spider-web," or silk, which is elaborated by little glands within the spider's abdomen and discharged through the six finger-like spinnerets at the posterior end. The web is a viscid fluid within the body, but hardens into threads on

exposure to the atmosphere. Spider's silk is very strong, and yet flexible. It is used by man for several purposes—as cross lines in surveyor's instruments, to swing the pendulums of very delicate and accurate clocks.

It is very interesting to watch an orb-weaver spin its web. First it climbs to some favorable spot and sends a floating strand of silk out on the wind. If the other end catches, the spider runs along the line several times, strengthening the first thread by adding other strands; then goes to the middle of its line, attaches a new strand, and drops to the ground, thus forming a new line from the middle of the first to the ground. By letting go new threads, and dropping down, and scrambling up, a couple of dozen lines are stretched. These meet at a point which is to be the center of the orb. After these "radii" are ready, a continuous spiral is spun from the center outward which forms a series of concentric cross connections between them. An orb-weaver is able to spin two kinds of silk, one of which is covered with little viscid droplets. Finally, two viscid threads are put on the radii between the concentric curves of the spiral.

The snare is now ready, and the spider takes position at the center, ready to dart out in any direction. If an awkward grasshopper or a careless fly blunders into the web, the viscid threads stick to it until the spider can run out and quiet the struggling victim by swathing it in silk. A spider, crouching at the center of its web, is able to see well in all directions, for there are eight little eyes on the top and front of its head. It is able to observe and pursue its prey with precision. The claws at the tips of the legs are admirably adjusted for running over the web and handling silk threads. Any animal captured is seized in the jaws and the secretion from the poison claws at their tips soon quiets it.

A spider has a small mouth and cannot eat large pieces of food. It sucks the juices of its victims and casts their shriveled bodies out of its web. At the end of the

esophagus there is a muscular sucking stomach which pumps the nutritive fluids from the prey. The food is digested to some extent in the large true stomach, and then passes on into the intestine to be acted upon further and absorbed. There are five large sacs, or cæca, connected with the stomach. These serve to increase its digestive and absorptive surface. Digestion is also assisted in the intestine by a number of pouches which branch out to such an extent that they fill most of the space within the abdomen.

After being absorbed the food is taken into the circulatory system; passes through sinuses and veins to the pericardial chamber. A spider's heart is wholly within the abdomen and is fastened to the walls of the chamber in which it lies by little elastic threads. These pull it out into an expanded condition after each contraction. While expanding the heart fills with blood through three pairs of lateral slits, or ostia. During contraction the blood is forced out through the arteries to all parts of the body. Backflow through the ostia is prevented by valves. Most of the blood coming to the heart has been purified by passing through the "leaves" of the book lungs, which are the respiratory organs of spiders. There is a pair of openings on the ventral side of the spider's abdomen, which lead into little chambers within the body in which the lung-books lie. Air is drawn in through the openings and passes between the leaves of the book, thus giving the blood within a chance to give up waste gases and acquire oxygen through the thin epidermal covering. The excretory organs of spiders consist of slender Malpighian tubules. Their free ends are closed and lie among the internal organs. Their proximal ends open into the intestine, and there discharge absorbed waste products.

Self-protection.—Spiders, like most predaceous animals, are solitary in their habits. They usually sit quietly in their webs waiting for prey. If danger threatens, a spider quickly seeks some retreat or drops to the ground. Before it goes, however, a thread is attached and a silken strand,

the ground line, is always passed out as the spider flees. After danger is past, the spider is able to return quickly and easily to its web by taking in the ground line.

The chief enemies of spiders are the mud-dauber wasps. One of these agile insects is able to pull an orb-weaver from its web and fly away without being entangled. The luckless victim of the raid is rendered torpid by stinging and used to provision the little earthen cells in which the wasp's eggs are laid. The spider guards against the wasp's attacks by spinning an irregular tangle of threads on all sides of its orb. These outlying lines impeded the progress of winged aggressors, or by their vibrations at least give warning that an attack is impending.

Spiders are subject to certain parasites and diseases which sap their vitality or destroy them outright. Such afflictions are more prevalent during damp weather. For many reasons rain is one of the spider's chief obstacles to success in life. Raindrops or heavy dews break down the web and on this account continual repairs are necessary.

Race Preservation.—Spiders are of two sexes, male or female. The latter is larger and spins the more perfect webs. When mature the little male frequents the webs of females in search of a mate (Fig. 59). The males of some species go through various fantastic courting activities, such as dancing, posturing, and posing before the female. Being a chosen suitor is a somewhat doubtful honor, however, for the female often eats the male, sometimes even before she has been fertilized.

After a female has received sperm cells for fertilizing her eggs, she usually makes elaborate preparations for cocooning. Some species of spiders carry their cocoons about in their jaws, or attach them to their abdomens; others hide them away under stones or logs. The orb-weaver goes to some sheltered nook in low vegetation and fastens her cocoon to the plants (Fig. 59). The gauzy structure is pear-shaped and hangs free from surrounding objects, suspended by silken threads. In the center is a

mass of eggs closely swathed in soft "woolly" silk and around this are two or three closely woven envelopes for protection. A mother spider usually dies soon after her cocoon is finished, but the young spiders, hatching within the envelopes she has furnished, are able to endure the winter and in the spring shift for themselves. The young of some spiders hatch in the spring, others in the autumn. Development within the egg usually requires only a few days but spiderlings may remain inside the cocoon for months.

On a warm spring or autumn day you will often find every tree and fence bearing long streamers of "cobwebs." These are the "balloons" of the young spiders. A cocoon may produce fifty young and it would not be desirable if they should all try to build orbs in the same bush. This difficulty is avoided by the ballooning instincts of the young. Soon after hatching they climb to some elevated situation, each lets out a long streamer of silk, and then jumps off into space (Fig. 59). The floating strands of silk are carried by the wind and the spiders may travel long distances. Thus each finds favorable hunting grounds, remote from numerous brothers and sisters. Spiders pass through a series of moults but there is no metamorphosis. The young are much like adults in their general form.

GENERAL REMARKS ON SPIDERS

If spiders are compared with their remote ancestors (Figs. 27, 28) it is apparent that they are highly specialized. The race has acquired many improvements in structures and methods. Though traces of segmentation are discernible in all the body regions, there are no free body segments. To secure greater compactness and rigidity all the segments have been united; the head and thorax have also fused to form a single region, the cephalothorax. The awkward abdominal appendages have been completely lost, the heart has become restricted to the abdomen, and there are many other evidences of racial specialization.

It is remarkable with what tenacity different groups of animals cling to the "styles" laid down for them by nature. There is no particular reason why an arthropod should have three or four pairs of legs—yet, there is no adult insect which does not have three, and no arachnid without four. Spiders all have spinning glands on the abdomen; insects possess such organs only during larval stages. Many insects have wings; no arachnids bear such appendages. The exact ancestry of spiders is somewhat uncertain. The earliest spider-like animals known lived in the shallow waters along the seashore. The fact that some arachnids (ticks, mites) have larvæ with three pairs of legs, however, has led some men to believe that spiders descended from insect stock.

In making adjustments to their surroundings, spiders display great acuteness in the development of their sense organs. They can perceive objects at a distance and jump at them with great speed and accuracy. They have many structural adaptations which enable them to vary their activities with changing conditions of life. But their mental powers are not highly developed. Their usual activities are simple movements or series of movements, which are repeated over and over if a certain set of conditions is repeated. Adjustments involving mental processes are simple. Peckham tells of a spider in his garden which dropped off its web when a tuning fork was sounded. It fell to the ground five or six times each day and then responded no more to the sound. It kept this up for fifteen days and then ceased to respond at all. Such behavior shows some ability to learn and remember. The processes involved are very simple, however, and do not allow us to assume that the mental powers of the spider rank very high among those of animals in general.

There are a number of different kinds of spiders and many differ greatly from the orb-weavers in their habits. The following are among the most important families: *Thomisidæ*, crab-spiders, spin no webs, but lurk in flowers

to capture their prey; many are colored so as to closely resemble the flowers in which they usually hide. The *Attidæ*, or jumping spiders, are very stocky. They do not spin webs but hunt over the surfaces of plants, buildings, etc. The *Drassidæ*, ground-spiders, and *Lycosidæ*, running-spiders, also spin very little, but seek small animals on the ground or among vegetation. Among the web-makers there are four important families. The *Agelenidæ* are the tube-weavers or tent-weavers, which make flat snares in the grass (Fig. 59). There is usually a little tube at one side in which the spider lurks. The *Lyniphiadæ* build flat irregular webs; the *Epeiridæ* make round orbs; and the *Theridiidæ* build irregular webs in the spaces among vegetation.

ORDER 2. SCORPIONIDEA

Scorpions (Fig. 60) are confined to the warmer parts of the earth. They are readily distinguished from other arachnids by the character of the abdomen, which is very slender behind and bears a poisonous sting at its tip. The sting is used for paralyzing small animals captured for food, but may also serve as a weapon of defense. Scorpions breathe through lung books, like spiders. They have many curious mating habits. Some species dance; in many the females carry their young about on their backs. When a scorpion stings a human being there are usually no serious consequences. The resulting irritation, pain, and swelling as a rule cease in a day or two, but in some instances even death may result. Stings are more serious for children than adults.

ORDER 3. PHALANGIDA

The phalangids (Fig. 60) are commonly known as "daddy-long-legs" or "harvest-men." They always have very long slender legs, the abdomen is distinctly segmented, and there is no slender "waist" between the cephalothorax

and abdomen, as in true spiders. Phalangids are nocturnal. They lurk in quiet nooks during the day and come out at night to feed on small insects and other animals. Their food habits make them beneficial to man.

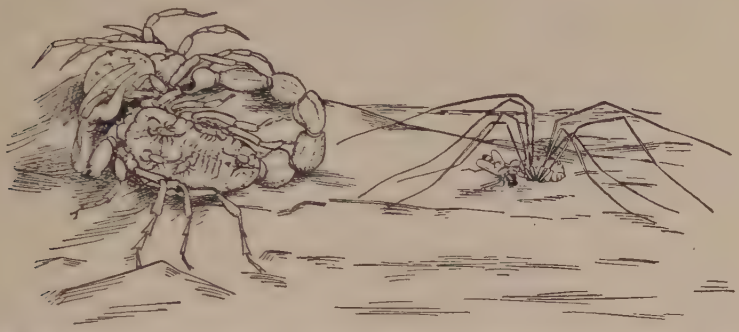


FIG. 60.—Scorpion carrying young and killing a spider; phalangid eating a fly.

ORDER 4. ACARINA

This order includes the mites and ticks (Fig. 61). These arachnids are wholly without external evidences of segmentation. The body is not even divided into regions, the head, thorax, and abdomen being fused into one mass. Many of the ticks and mites are parasitic in their habits and some carry diseases. All are able to go for long periods of time without food, sometimes for as much as three or four years.

The mites are all of small size and their bodies are never greatly swollen. There are several important species in the United States. The poultry mite, *Dermanyssus gallinæ* sucks the blood of fowls and annually causes great losses. The chiggers, or harvest mites, *Trombididæ*, are common on low vegetation and hence often get on men working in fields. As six-legged larvæ, they commonly attack the skin and cause severe irritation. Preventative measures consist in sprinkling powdered sulphur or naphthalene in the underclothing. Bites are treated with ammonia or weak carbolic solution. The disease known as scabies or

seven-year itch, is caused by a mite, *Sarcoptes scabei*, which lives in little tunnels in the skin. Another mite, *Demodex folliculorum*, commonly lives in the oil glands of the skin, particularly those on the nose and face, but apparently does no harm. The scab-parasite, *Psoroptes communis*, attacks sheep, cattle, and horses, causing sores on the skin.

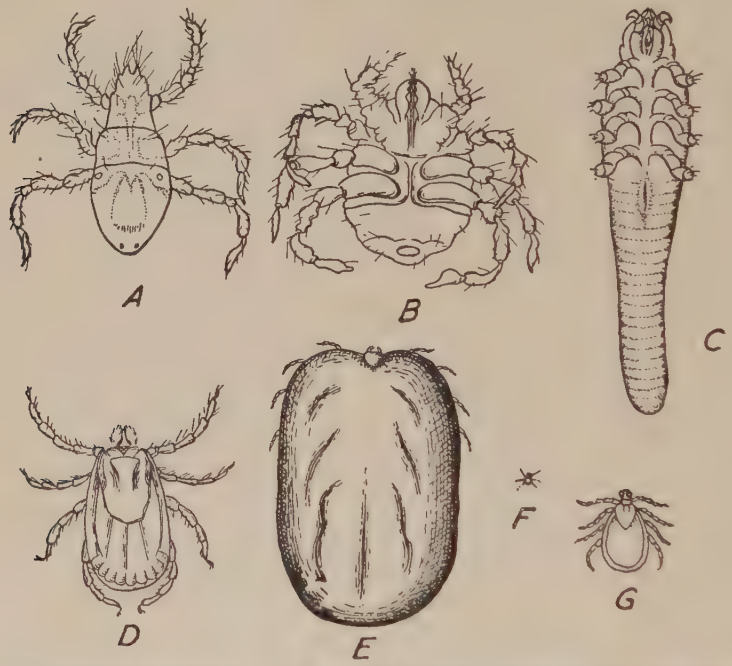


FIG. 61.—Mites and ticks. A, B, nymph and adult of chigger, or harvest mite; C, the follicle mite, *Demodex*; D-G, ticks: male, female, larva and nymph.

Ticks are larger than mites and adult females become greatly swollen, some reaching the size of a lima bean. The cattle tick, *Margaropus annulatus*, is the best known representative in this country. An adult female of this species, after filling herself with blood, drops to the ground, and lays several thousands of eggs. As soon as the six-legged "seed ticks" hatch, they climb up to the top of the nearest grass and await the passing of some animal which

may serve as a host. If need be, they remain thus on the alert for several months, patiently waiting through wind, sun, and rain. If the larva succeeds in attaching itself to a cow or some other animal, it feeds, and then moults to become an eight-legged nymph. The nymph takes another meal and sheds its skin to emerge as an adult tick. There are a number of species of ticks in the United States. They attack man, poultry, and other animals.

Though ticks may cause some trouble and inconvenience by sucking blood, their chief claim to economic importance lies in their ability to transmit diseases. The cattle tick carries Texas fever. This disease is caused by a protozoan parasite, *Babesia bigemina,* which not only flourishes inside a tick in the blood sucked from an infected animal, but may also be transmitted by a female tick to her offspring. The national government has recently worked out methods for the eradication of Texas fever. One of the best is the rotation of cattle through several pastures so as to free them from ticks. The disease has caused losses amounting to $100,000,000 in a single year in the United States. Another tick, *Dermacentor andersoni,* is prevalent in certain parts of the northwestern United States. It carries and transmits the spotted fever, or mountain fever, a fatal disease. In West Africa ticks are very numerous and carry most of the prevalent fevers affecting man and other animals. Several cases have been recorded in America in which paralysis occurred in persons bitten by ticks.

CHAPTER XII

PHYLUM PROTOZOA

Protozoa are single-celled animals. In many species great numbers of cells are grouped together to form colonies, but in such cases there is no division of labor between the cells; tissues are not formed, as in true many-celled animals. A protozoon, then, has all the characteristics of single cells as described in Chapter IV. Each protozoon, though consisting of but a single cell, is able to feed, escape dangers, reproduce, and carry on all the activities characteristic of living things (Chapter III). Most protozoans are very small and can usually not be seen without the aid of a microscope. But what they lack in size is made up in numbers, and there is no bit of natural water or soil without them. They often swarm by myriads in fields, lakes, rivers, puddles, eave troughs, cisterns, water pipes, and other wet places. Many species live as accidental guests or as parasites in the bodies of many-celled animals, some even causing important diseases of man and the domestic animals.

There are four classes of Protozoa, arranged primarily according to methods of locomotion. They are as follows:

1. Sarcodina (Rhizopoda). Protozoa in which locomotion is by means of rather blunt protoplasmic projections called *pseudopodia.*

2. Mastigophora. Protozoa which have whip-like *flagella* for locomotion.

3. Sporozoa. *Parasitic* protozoans possessing no special locomotor organs, and in which there is at times a formation of many spores for reproductive purposes.

4. Infusoria. Protozoa which have the body covered with many hair-like *cilia* for locomotion.

CLASS I. SARCODINA

The Sarcodina are naked cells (Fig. 62, A–D). Many have shells secreted around their little bodies, but such accretions are not actually a part of the protoplasm. The protoplasm of these animals is, then, without much specialization, but it may form elaborate structures on the outside. The amœba will be considered as a representative of the Sarcodina.

THE AMŒBA

Self-maintenance.—There are a number of different kinds of amœbas and their structure and habitats vary considerably. The species chosen for the subject of this discussion, *Amœba proteus* (Fig. 62, A), is found in water, in the brown coating of microscopic plants such as accumulates in water troughs and among aquatic vegetation. Its food consists of minute plants and animals which are engulfed by the soft body. There is no mouth or definite place for the entrance of food. The body consists, like all cells, of a central nucleus surrounded by cytoplasm. The cytoplasm is of about the consistency of the white of an egg, and shows a differentiation into two regions: an outer denser portion, the ectosarc, and an inner granular portion, the endosarc. When an amœba engulfs its food the ectosarc is first turned in to form a little pocket, then surrounds the food completely. The object eaten goes into the endosarc, surrounded by a little water and the ectosarc which came in as it was being engulfed. The watery secretion formed around the particle makes a "food vacuole," and contains certain substances which dissolve the food so that it may be gradually absorbed by the surrounding endosarc. If there are substances in the food which cannot be digested and assimilated, they are dropped out from the body anywhere, as the amœba moves along. In spite of the extreme simplicity of the amœba's body, it is able to discriminate between objects fit for food and those which are unsuitable. It rejects sand

grains or other worthless particles, but persistently follows moving animals or plants which may serve for food. Such behavior shows that the amœba has a simple "chemical sense," or what corresponds to taste and smell in higher animals.

After food has been absorbed, it flows about in the endoplasm so that all parts are supplied with nourishment.

Fig. 62.—Protozoa. A-D, Class Sarcodinia; E-G, Class Mastigophora; H-K, Class Infusoria. A, *Amœba;* B, *Arcella;* C, *Diffiugia;* D, *Actinosphærium;* E, *Mastigamœba;* F, *Euglena,* G, *Volvox;* H, *Paramœcium;* I, *Vorticella;* J, *Stentor;* K, *Stylonychia.*

The amœba is less than a thousandth of an inch in length and therefore does not need special adaptations for respiration. Waste gases are shed into the surrounding water and oxygen is readily absorbed. Waste products resulting from metabolism are dissolved in the water fluids within the body and flow into a little reservoir, the contractile

vacuole, which pulsates regularly and empties its accumulated wastes through several pores opening through the ectosarc.

Self-protection.—The amœba is so small that it has few enemies. It could not run away very successfully if pursued, for it moves very slowly by projecting little soft finger-like pseudopods on which it walks or flows along. Sometimes one amœba will chase another and eat it.

The worst dangers for amœbas, however, are the changes in physical conditions which may come with the drying up of the water in which they live, or with the changing seasons. If such unfavorable changes do not come too suddenly an amœba secretes a resistant covering about its body and remains in a quiescent state, biding its time until conditions are again favorable. Such a resting amœba is said to be encysted, and is called an amœba cyst.

The amœba lives from day to day so as to escape ordinary dangers as far as possible. It is wholly without anything which may be interpreted as an eye, yet is sensitive to light. This sensitiveness is of use to the amœba in enabling it to avoid the direct rays of the sun, which would be injurious, and allows it always to creep away from the light into dark crevices where it finds food and shelter. The amœba is therefore protected from harm because it seldom comes out into the open.

Race Preservation.—For an amœba, the formation of new individuals is an easy matter. One individual has only to undergo cell-division to produce two, and if each of the "offspring" produced in this way continues to divide at intervals, the final total will be enormous. When an amœba divides, the body forms two cells of equal size and hence the process is known as binary fission. Such fission may continue to be the only means of multiplication for several hundreds of generations, but if continued too long the last generations lack vitality and the stock finally dies out. An amœba, therefore, does not pass through its life cycle as an individual. Starting with a "young" individual it divides

in the succeeding generations to form other amœbas and after a time maturity, old age, and death are attained. Any one individual is young, or mature, or old, through all its "life."

If binary fission were the only process concerned in the reproduction of amœbas, they would probably all have died of old age long ago. But there is another way in which individuals may be produced. This is by conjugation. At intervals two amœbas come together and, after a preparatory or ripening process, exchange some nuclear material. When they separate again they are not the same, for each contains part of the other. There is also another and more important change resulting from conjugation. After it is completed each of the conjugants is young, no matter what its condition was before. An amœba may be mature or in the last stages of old age, and after conjugation be rejuvenated, starting anew with all the vigor of youth.

When compared with other rhizopods (Fig. 62), the amœba shows great simplicity of structure. It is a bit of naked protoplasm with a nucleus and a contractile vacuole. Some of its relatives have little shells about the body. *Arcella* (B) has a hemispherical shell composed of chitin; *Difflugia* (C) encloses itself by sticking sand granules together to make a beautiful little case. In one order of rhizopods, the Foraminifera, a calcareous shell is secreted within the cytoplasm of the cell. These shells are of various forms in different species—like rods, wheels, strings of beads, etc. The largest protozoan known is a fossil foraminifer, Nummulites, which is disc-shaped and sometimes has a diameter of about two inches. Chalk deposits like those at Austin, Texas, are made up mostly of the shells of Foraminifera. The rhizopods in the order Heliozoa (D) do not have a shell but possess very slender pseudopodia which radiate from the body and have permanent rod-like supports in them. The Radiolaria are marine rhizopods which have slender pseudopodia like

those of the Heliozoa, and also have elaborate basket-like internal shells of silica.

Some amœbas cause important diseases of man and other animals. *Entamœba histolytica* burrows in the wall of the intestine, swallows red blood corpuscles, and is the cause of dysentery; *Entamœba gengevalis* is associated with pyhorrhea alveolaris, a very prevalent disease of the teeth.

CLASS II. MASTIGOPHORA

Mastigophorans (Fig. 62, E–G) all have one or more flagella for locomotion, and on this account are commonly known as flagellates. A flagellum is a slender hair-like process which pulls the cell along by lashing about. In addition to this locomotor appendage, the Mastigophora are generally to be distinguished from the Rhizopoda by the presence of a membrane, or pellicle. This is a thin outer covering which, though it may be pliable, gives the body a more definite form. The simplest mastigophorans, however, lack such a covering. Mastigamœba (Fig. 62, E), for example, is much like an amœba with a single long flagellum. Its body is naked, and it can crawl about by protruding pseudopodia, but it may also swim actively through the water by moving its flagellum.

Many mastigophorans show relationships to plants. All green plants contain chlorophyll, a substance which is able in the presence of sunlight to elaborate organic compounds (starch, etc.) from simple substances like carbon dioxide and water. Such "manufacturing" is known as photosynthesis. Many of the protozoans in this class contain the green chlorophyll and are able to carry on photosynthesis like that in plants. Another indication of relationship between mastigophorans and plants is the fact that the motile stages (swarm spores) of a number of the simpler plants are very much like free living mastigophorans which do not come from plants. We have at one extreme, mastigophorans which are clearly animals, and at the other,

flagellated organisms which are clearly plants. On account of such mixed relationships some biologists make a group, Flagellata, which contains both plants and animals, and which is believed to have given rise to plants by emphasizing certain qualities, and to animals by stressing others. According to this view the flagellates were the first living things and hence stand at the base of the evolutionary series. A form like the Amœba may, therefore, not be primitive, even though it is simpler in structure than any other animal, but perhaps may have arisen from the more complex flagellates by the loss of some structures. Mastigamœba in such an evolutionary history might serve as a "missing link."

Some flagellates almost become metazoans. There are many species in which colonies are formed by cells remaining united after fission. In such colonies the number of cells may be variable or very constant. In certain species there are always four, eight, sixteen, or thirty-two cells. Others have a very large number; a colony of Volvox (Fig. 62, G), for example, may be made of 12,000 cells. In colonies of flagellates there is often a division of labor between the cells —some carry on locomotion and feeding, others serve for reproduction only. There is thus a differentiation into somatic (body) and germ (reproductive) cells. In Volvox and some other colonies there is a further division of labor in the germ cells; some developing into large ova (eggs) and others into small sperm cells. This, however, is the limit of cell-specialization in flagellates, or in protozoans, and the colonies cannot properly be classed as many-celled animals because the somatic cells are all alike—*i.e.*, there are no tissues.

There are a number of flagellates which cause serious diseases. Different species of the genus Trypanosoma cause sleeping sickness in man, surra and dourine in horses, nagana in cattle, etc. The Texas fever which is prevalent in cattle in the southern United States is caused by an organism which passes through a flagellate stage. There

are several species which live in the alimentary canal of man and other animals.

CLASS III. SPOROZOA

This group of protozoans contains only species which are entirely parasitic, and they may live in representatives of any phylum of the animal kingdom. There are some which even dwell in the bodies of other protozoans. As would be expected from their parasitic habits, many sporozoans cause diseases in the animals they inhabit. The sporozoan disease of most interest to man is malarial fever, prevalent in all the warm regions of the earth.

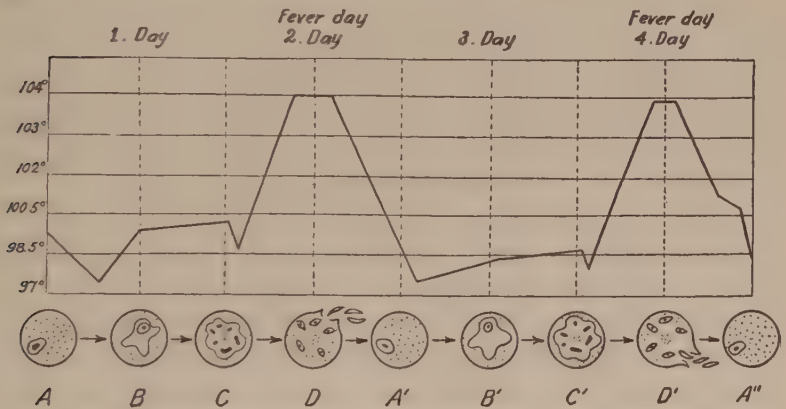


FIG. 63.—A temperature chart of a man sick with malarial fever, and (below) red blood corpuscles containing the parasites causing the disease. Note that there is high fever when an infected corpuscle ruptures, thus freeing spores, poison, and black pigment. A, A', A'', young Plasmodium in corpuscle; B, B', well grown; C, C', nearly mature; D, D', ripe spores escaping.

Malaria is caused by parasites of the genus Plasmodium and there are three different species which cause characteristic fevers. *Plasmodium vivax* causes "benign tertian malaria" (*i.e.*, mild malarial fever in which there is fever every third day). This parasite can enter a man only when a certain mosquito bearing the disease bites him, and it then migrates from the insect's proboscis directly into the blood. Once in the blood it enters a red corpuscle and grows for

about a day and a half, then divides into several little spores (Fig. 63). The infected corpuscle finally bursts open, setting the spores and a poison free in the blood. The poison causes the febrile condition which a patient shows. The little spores enter new corpuscles, grow for two days, and then release another crop of spores. There is thus a periodic recurrence of fever, every third day, which is correlated with a certain stage in the development of the parasite.

Three things are necessary before malaria can become established in a region: (1) infected people, (2) anophelene mosquitoes, and (3) warm climate. A man may carry the parasites and serve as a "reservoir" long after he has ceased to have fever. The mosquito cannot transmit the disease as soon as it draws blood from an infected person, but must "incubate" the parasite for about twelve days. During this incubation period the germ cells of the parasite conjugate and young spores are produced which take up their position in the mosquito's salivary glands, ready to enter the next man who is bitten.

CLASS IV. INFUSORIA

In this class of protozoans cilia are the characteristic organs of locomotion (Fig. 62, H–K). Cilia are much like flagella, but are smaller and always occur together in large numbers. There is always a cell-membrane or pellicle covering the body of a ciliate and two nuclei are usually present. The larger, or trophonucleus, is concerned with ordinary metabolic activities; the smaller micronucleus is usually active only during fission or conjugation. The cells of some ciliates are the most complicated in the animal kingdom. It will be well, therefore, to consider the activities of a typical representative in some detail in order that it may be compared with the amœba (page 135), which is one of the simplest of cells. For this purpose the "bell animalcule" *Vorticella*, is chosen.

Vorticella campanula Ehrenberg

Self-maintenance.—Vorticella (Fig. 62, I) is to be found in fresh-water ponds and ditches attached to some object by a slender stalk. The specific name, campanula, refers to the shape of the body, which resembles a dinner-bell with a very long handle. Around the distal margin of the bell there is a row of cilia. These by their continual beating create a vortex in which the water is drawn toward the mouth—hence the generic name, Vorticella.

This little protozoan feeds on minute particles brought to it in the currents created by the cilia. If unsuccessful when drawing water from one source, it jerks back by contracting and coiling the stalk, and then stretches out in a new direction, thus increasing its chances of finding organisms on which it may feed. There are little contractile strands passing from one end of the stalk to the other, and these are just as much specialized for contraction as the fibrils in the muscle cells of a vertebrate. Food particles enter the mouth and, after passing through a short gullet, are enclosed in a little food vacuole before beginning to circulate in the endoplasm. Undigested food passes out through a definite opening in the pellicle. There is a contractile vacuole near the distal end of the bell, which serves for excreting metabolic waste products. The trophonucleus in Vorticella is large and U-shaped. It thus extends through a considerable part of the interior and can readily control metabolism.

Self-protection.—Vorticella has few enemies. There are some sporozoans which live within it as internal parasites. Some protozoans and larger animals feed upon it. It cannot run away when set upon; its only method of escape is to shorten the stalk as much as possible and remain quiet until danger is past.

If the conditions of life are unfavorable in a certain place, a Vorticella may break loose from its stalk and swim to some better spot, where it forms an attachment and grows a new

stalk. If conditions become unfavorable everywhere, a wall is formed around the body, and encystment takes place. Vorticella can then remain in a quiescent condition until better times come.

Race Preservation.—Vorticella can produce new individuals by fission. The trophonuclei and micronuclei elongate and divide, the bell becomes wide, and a constriction appears at the distal end which splits the cell longitudinally into two parts, each with a pair of nuclei. Two individuals are thus formed, attached to one stalk. One of them soon forms a second band of cilia about its body, breaks loose and swims away to settle down and form a stalk of its own. Vorticella may multiply for many generations by such binary fission but will finally die of old age unless conjugation takes place.

For conjugation two kinds of individuals are formed, macrogametes and microgametes. The former are stalked individuals differing neither in size nor in any other obvious feature from an ordinary Vorticella. The microgametes, as their name implies, are much smaller. They are also peculiar in possessing a posterior circle of cilia about the body and in being without a stalk. A microgamete when set free from the "parent" (by cell-division), swims about until it finds a macrogamete and then conjugates. Conjugation begins at daybreak and lasts thirteen or fourteen hours. The cytoplasm of the macrogamete fuses with that of the microgamete. The trophonuclei in both cells then degenerate and take no part in what follows. The micronucleus in each cell, after dividing several times in order to cast out some of the nuclear material, is ripe, and then fuses with a nucleus formed from the micronucleus originally in the other cell. Thus a single new cell, the zygote, originates from the macrogamete and the microgamete, which were two separate cells at the beginning of conjugation.

When compared with those in the amœba, the conjugating cells in Vorticella show progress along the line of sex differentiation. The small motile microgamete has male

characteristics; the larger stationary macrogamete is the female. Vorticella is not as specialized in this particular as some of the flagellates and sporozoans (Volvox, page 140; Plasmodium, page 141).

GENERAL FACTS ABOUT PROTOZOA

Protozoa are remarkable among animals because their entire bodies consist of single cells. Some of them are the most complex animal cells known, others are the most simple. Metabolism in many protozoans is extremely rapid. One species, *Didinium nasutum*, can devour other protozoans that are ten times its own size, the body becoming stretched so that it forms a thin covering for the food, yet in an hour or two it is ready to eat another meal of similar size.

It is often said that "the Protozoa are immortal," and this may indeed be true of most species. When a protozoan cell is about to die of old age, it may become young again by conjugation or by fusing with another cell, but must, of course, sacrifice its identity by so doing. This is not true, however, of protozoans in which there is a differentiation into somatic (body) and germ (reproductive) cells, (*Volvox*, *Plasmodium*). In these, as in many-celled animals, the "body" must die and only the germ cells may help to form a new generation. The statements in regard to the necessity for conjugation in order to attain youth would probably not be accepted by Professor L. L. Woodruff, who has reared a ciliate (*Paramœcium*) for more than five thousand generations without conjugation. In a recent paper (1916) he says: "an individual of Paramœcium is self-sufficient to reproduce indefinitely without recourse to conjugation." If Woodruff's point of view is accepted, it may be necessary to revise completely the current ideas in regard to the production of youth, or it may be found that only a few protozoans are able to multiply indefinitely by fission without dying of old age. Perhaps the latter alternative may be looked upon as the more probable for among many-celled

animals there are only a very few cases of parthenogenesis, or development of ova without fertilization, and considering the whole animal kingdom there are very few cases in which new individuals do not originate from zygotes. Another view regarding the effects of conjugation has been advocated by a number of zoologists, *i.e.*, "it is more probable that conjugation results in increased powers of adaptability than in rejuvenescence."

If protozoans are always single cells, it is but natural to ask what their psychic capabilities may be. Can they profit by experience? Have they memory? In connection with the discussion of Amœba and Vorticella it has already been shown that protozoans can vary their behavior somewhat to meet changes in surrounding conditions, but for the most part their activities are simple and are repeated over and over if stimulating conditions are repeated. A free-swimming individual will start in a certain direction and keep going until it finds food (or a mate, if the breeding instincts are active). If some unfavorable stimulus is encountered, however, it backs up a little and starts off in a new direction. If conditions are again unfavorable, there is more backing and trying, until a proper course is found. The life of an active protozoan, then, is a series of continual testings of the surroundings; success is attained by holding to what promises to be good and avoiding what appears to be bad. There is no reasoning, no planning or forethought.

The Protozoa present one other point of general interest—they were doubtless the ancestors of the Metazoa. Many protozoans have almost become many-celled animals, in fact, it is hard sometimes to draw the line between single and many-celled forms, but none have quite attained the goal. Most of them have taken the wrong road by specializing the structures of single cells, instead of forming a group of cells and dividing the work to be done among them. Perhaps many-celled animals have arisen from more than one group of protozoans. The possible steps by which the Metazoa arose will be considered in the next chapter.

CHAPTER XIII

THE ORIGIN AND CHARACTERISTICS OF THE METAZOA

ORIGIN OF MANY-CELLED ANIMALS

There is every reason to believe that Metazoa arose from Protozoa; *i.e.*, that single-celled animals gave rise to many-celled animals. There is no fossil record of such a transformation because the earliest geological strata on the earth have all been modified so that their records are destroyed. The first records show single-celled animals living with many-celled types, as they do today. Yet the development of every metazoan starts with a single cell and the law of biogenesis (Chapter V), therefore, indicates that the origin of Metazoa was from single cells. Furthermore, all the processes that take place in the development of a metazoan, up to the formation of tissues, are duplicated in protozoans. There is a general direction which all cell associations take, and metazoans have simply gone farther than protozoans.

With these things in mind, it is possible to give a synopsis of the probable steps in the origin of many-celled animals. First, groups of cells arose as a result of the ordinary multiplicative processes in protozoans—binary fission. The cells after dividing did not separate but remained united. After a time such behavior became the regular procedure in certain strains of protozoans and colonies of cells always resulted from cell-division. This gave opportunity for the next step—division of labor between the cells. Some were set aside to carry on cell multiplication and reproduction, others looked after the nutritive and protective functions. This specialization was a convenience for the whole colony, for each individual cell had fewer things to attend to. This

differentiation into soma and germ had, and still has, one disadvantage, however—all the somatic cells must die when the body is worn out.

After germ and somatic cells were established another improvement came in, by dividing the labor between the sexual cells. As stated in the last chapter a *young* individual is produced by the fusion of two sexual cells to form a single cell. It is desirable, if two sex cells are going to fuse, to have them able to move so that they can more readily get together. It is also desirable that they contain reserve energy, so that development may go on after fusion has taken place, during the time when the usual activities are more or less disturbed. Locomotion and storage of nourishment are therefore two essential qualities in germ cells. It is not very feasible, however, to have a cell store large quantities of food and at the same time be able to move about readily. This difficulty has been met by the development of two kinds of germ cells: (1) ova, which are large, immobile, and contain much nourishment; and (2) spermatozoa, which are minute and very active.

In a number of groups of protozoans colonies of cells have become differentiated to the extent described up to this point, but only true metazoans have differentiated the somatic cells so that tissues are formed. Tissues are, therefore, the only criterion which will separate one group from the other. If, in the future, some colony of protozoans develops a division of labor in its somatic cells, so that one group attends to one function and another group to some other activity, we will then be obliged to classify it as a many-celled animal.

TISSUES AND ORGANS

A tissue is a group of similar cells which carries on some particular function in a metazoan's body. Tissues have developed chiefly along four lines, and each of the chief types has arisen by emphasizing some quality present in all protoplasm. The groups are as follows:

1. *Epithelial tissue* consists of thin sheets of cells which usually cover surfaces. The external covering of metazoans consists of epithelial tissues and their products; the linings of various internal cavities and the membranes which connect different organs are usually epithelial.

2. *Muscular tissue* has specialized by developing its power of contractility. The simplest muscular tissues are made up of elongated single cells, but the more elaborate types, like the striated muscles of arthropods and vertebrates, are extremely complex and have various special adaptations for making them contract more effectively. There is one point to remember in regard to muscular tissue—it can only do work when contracting.

3. *Nervous tissue* is composed of cells which have greatly developed their powers of conducting and modifying impulses. Most nerve cells have long fibers leading out from the cell-body and these carry nervous impulses from place to place. Ganglia are places in nervous tissues where there are more cells then fibers, and they serve as "relay stations" for modifying or originating impulses. Nerves are portions of nervous tissue which contain few or no cell-bodies, but have many fibers.

4. *Sustentative*, or *Connective tissue*, is quite variable but is always characterized by the presence of a large amount of intercellular substance. This material between the cells may be bone (in osseous tissue), fibers (fibrous tissue), cartilage (cartilaginous tissue), plasma (blood), or other matter.

In the bodies of most many-celled animals division of labor has been carried beyond the formation of tissues. Usually organs are formed by grouping various tissues together for carrying on particular labors. The heart, for example, is an organ for pumping blood, and is composed of muscular, epithelial, fibrous and nervous tissue. The hand is an organ for prehension and offense; it is made up of bone, cartilage, muscle, nerve, epithelium, etc. Organs in the more complex animals are in turn grouped into

great systems which are chiefly as follows: digestive, circulatory, respiratory, excretory, muscular, skeletal, nervous, reproductive.

REPRODUCTION IN METAZOA

It has been said that all Metazoa start as single cells, and in general this statement is true, but there are many exceptions in particular cases. In fact, it may be said that there are two methods of reproduction—*sexual* and *asexual*. The former always involves the union of an ovum and a spermatozoon to produce a new and young individual. Asexual means without sex, and there are various ways in which new individuals may be formed without the usual fusion of germ cells. Some sponges may be cut up in pieces and propagated as slips, like plants; others give off groups of cells as buds, and these grow into new individuals, still others have the bulk of the body decay at certain seasons, but at such times groups of cells in the interior form a resistant coating, live until they can have opportunity to grow again, and then form a complete new sponge. Various polyps and worms are able to produce new individuals by budding off portions of the body or by breaking it in two.

In addition to usual asexual methods of reproduction, there are among metazoans some modifications of sexual processes. Many-celled animals show two conditions in regard to sex—they may be *hermaphroditic* or *diœcious*. In the former case an animal has both male and female organs in its body, and in rare instances is able to fertilize itself. It can thus sometimes produce offspring without the presence of another individual. There is another modification of sexual reproduction shown in *parthenogenesis*. An ovum will usually not develop unless it has united with a sperm cell but there are a few animals in which such union may not be necessary, and ova therefore develop without fertilization. However, in most cases, perhaps in all, parthenogenetic reproduction cannot go on

indefinitely, but must give place occasionally to sexual processes, and the great majority of animals cannot reproduce parthenogenetically at all.

In spite of the various ways in which individuals may arise, the development of any particular metazoan from a fertilized ovum usually shows a rather definite sequence of events, and this series of stages is practically the same in all the different phyla, except one. Before passing on to the phyla of metazoans, it will be proper therefore to consider a typical developmental history.

ONTOGENY OF A TYPICAL METAZOAN

1. *Maturation* (Fig. 64, A, B).—A many-celled animal starts as a single cell, the zygote, formed by the union of the egg cell, or ovum, with a sperm cell, or spermatozoon. Before a zygote can be formed, however, there must be certain preparatory or ripening changes in both the egg and sperm, and such changes are known as maturation. The egg cell during its maturation undergoes mitotic cell division twice; but at each division (*b*, *c*), instead of two cells of equal size being formed, one cell is very large and the other minute. The smaller cell is known as a "polar body," and is to be looked upon as a rudimentary egg which has been sacrificed in order to leave the functional egg as much nourishment as possible. The maturation of the sperm cell (B) consists also of two successive cell divisions (*b*, *c*), but in this case four functional spermatozoa of equal size are formed (*d*), each bearing a little tail for swimming.

But, you ask, why not have the egg and sperm fuse at once without ripening—why have maturation at all? There is apparently but one important thing involved. During the two cell divisions chromatin material is eliminated and the number of chromosomes is reduced to one-half the somatic number. If the somatic cells in a particular animal showed ten chromosomes during mitosis, a ripe germ cell would have only five.

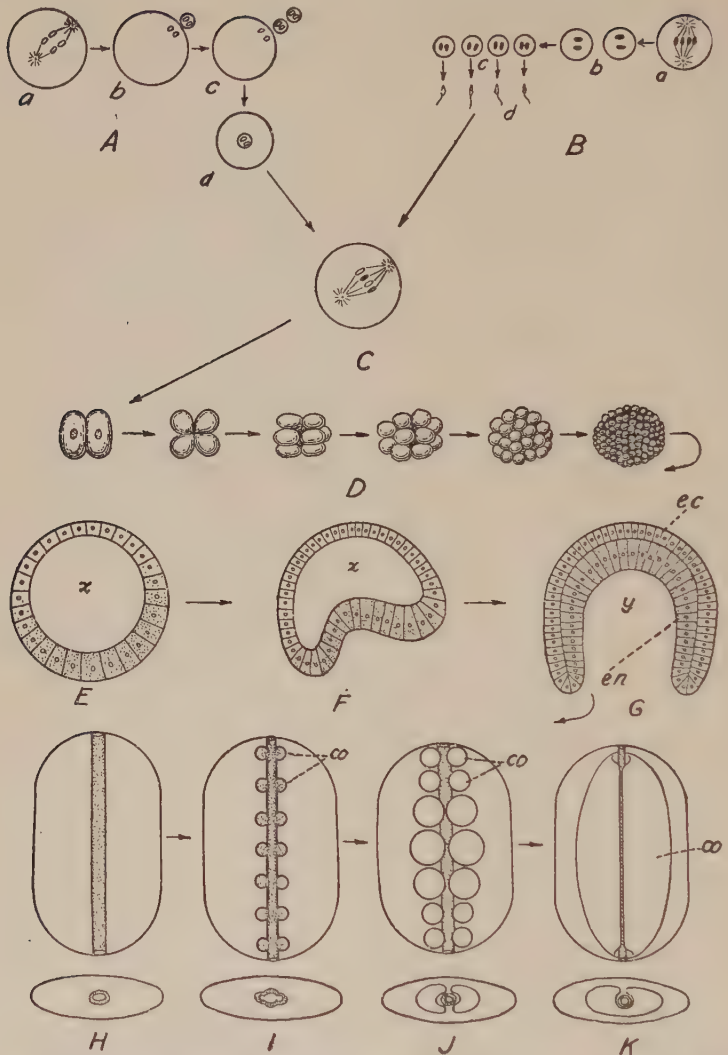


FIG. 64.—Scheme for the developmental stages of a metazoan. A, B, maturation of egg and sperm cells—*a*, first division; *b*, two cells resulting from division; *c*, cells after next division; *d*, ripe egg or sperm cell. C, zygote formed by union of ripe egg and sperm, now dividing. D, cleavage stages. E, section through blastula stage—the stippled cells represent the portion to become entoderm. F, section during gastrula formation; *x*, cleavage cavity. G, section through mature gastrula; *ec*, ectoderm; *en*, entoderm; *y*, archenteron, or primitive digestive cavity. H, young metazoan with tubular digestive system. H–K, stages in the formation of the cœlom or body cavity; the lower figure of each stage represents a cross section of the one above; *co*, cœlom.

2. *Fertilization,* or the Formation of the Zygote (C).—After maturation, the sperm cells move to the eggs, if conditions permit, and fuse with them. Only one sperm cell unites with each egg, though many may try. The sperm cell is always much smaller than the egg. Sometimes its bulk is only one five-hundred thousandth that of the ovum with which it unites. It usually pierces the cytoplasm of the egg for a short distance. Before fertilization takes place both the germ cells have half the somatic number of chromosomes. When the sperm enters the egg, it brings chromatin and chromosomes equal to those in the egg, and the somatic condition is thus restored in the zygote.

3. *Cleavage.*—Soon after the sperm cell has entered the egg chromosomes are formed in both egg and sperm nuclei, a spindle is originated from the centrosomes of the sperm nucleus, and the chromosomes take position around its equator (C). These chromosomes are half from the sperm cell and half from the egg. The usual steps in mitosis (page 40) are now completed and the "fertilized egg" or zygote, thus divides into two cells. This division is known as the first cleavage. There follow two-, four-, eight-, sixteen-, thirty-two-celled "cleavage stages" (D); and others involving even larger numbers of cells. After a time a little ball of cells, the *morula,* is formed and this later becomes hollow by having a water-filled "cleavage cavity" (*x*) form in the middle. Such a ball of cells with a central cavity is called a *blastula* (E). It soon changes to a gastrula by the turning in of one side.

4. *Gastrulation;* the Formation of the *Germ Layers.*—When the side of the hollow spheroidal blastula is turned in, the cleavage cavity (*x*) is encroached upon and is finally completely obliterated because the turned in portion comes in contact with the epithelium on the other side of the original sphere (F, G). The result is a concave hemisphere made up of two layers. The epithelium covering the outside is the ectoderm (*ec*); the cavity within is the

archenteron (*y*), or primitive digestive cavity, which is lined by the inner epithelium or entoderm (*en*). The ectoderm and the entoderm are the primary germ layers, and the metazoan is now a gastrula (G).

Some animals (Fig. 68) are adults in the gastrula stage and their development goes no farther. They remain in a diploblastic, or two-layered, condition all their lives and the archenteron serves their simple digestive needs. Most metazoans, however, have a third layer, the mesoderm, formed between the ectoderm and entoderm, and also have modifications of the archenteron so that, instead of having only one opening for the ingestion and rejection of food, a mouth and anus develop. During the gastrula stage, or soon after, metazoans take on the distinctive characteristics of the phylum to which they belong. A cœlenterate remains a gastrula but forms tentacles, stinging cells, and other structures proper for its adult life. Most flatworms develop a great mass of mesodermal cells but retain the original opening into the archeneteron for feeding. More highly specialized animals develop far beyond the gastrula stage; the three germ layers becoming greatly modified by thickenings, the formation of cavities, foldings, and in other ways.

5. The *Formation of the Cœlom*, or *Body-cavity*.—After passing through the gastrula stage a cœlomate animal develops a tubular digestive system, the original entrance into the archenteron serving as one opening and a new aperture forming by breaking through at the opposite end (Fig. 64, H). Although there is some variation in the way the cœlom arises in different groups of animals, the following description will serve to illustrate the general method. Pairs of little pockets form along the sides of the alimentary canal and push out against the body wall. The cavities in these later lose their connection with the alimentary canal (taking the form of closed sacs), then enlarge greatly so as to envelop all the internal organs (J), and fuse together (K). Thus a large space, the cœlom

(*co*) is formed between the body wall and that of the digestive tube. Organs which develop later as outgrowths from the alimentary canal must push aside the membrane lining the cœlom, and on this account the membrane envelops all the internal organs closely. For example, the peritoneum, or lining of the cœlom, surrounds all the abdominal organs in a man's body. This makes it difficult to perform surgical operations, for, if bacteria gain access to the cœlom, they will cause peritonitis (inflammation of the peritoneum) and the infection will wander about among the internal organs, usually causing death.

6. The *Formation of Systems of Organs.*—The germ layers play rather definite rôles in subsequent development. The nervous tissues and the outer integument, or skin, always arise from the ectoderm. The entoderm forms the lining for the middle portion of the alimentary canal, or midgut, the notochord, and the lungs. Other tissues and systems of organs take their origin chiefly from the mesoderm. The greater part of the body is therefore formed, in most animals, from the middle germ layer.

This brief synopsis indicates the chief steps in metazoan development: Maturation, fertilization, cleavage, gastrulation, and cœlom formation. The first three stages occur in protozoans as well as metazoans, but it is only in many-celled animals that tissue differentiation takes place after the formation of the primary germ layers by gastrulation. As has been stated, some metazoans never get much beyond the gastrula stage, but even those that pass on to more specialized conditions (cœlom, paired appendages, chorda, etc.) follow the regular route through the stages of maturation, fertilization, cleavage, and gastrulation. This persistent adherence to one conventional type of development is believed to indicate genetic relationship among animals. According to the Law of Biogenesis, therefore, metazoans arose from protozoans; all were at one time (and some still are) gastrulas, and many have through specialization gone farther. The racial development of all the

phyla of animals was, therefore, probably the same up to the gastrula stage (with one exception, and this will be considered in the next chapter).

Aside from the development of the cœlom, the most important advances in the recent racial history of animals are: (1) The ascendency of the bilateral type of symmetry. (2) The development of paired appendages. (3) The more "progressive" bilaterally symmetrical animals are all metameric, and the simpler metameric types consist of a similar series of segments from the anterior to the posterior end. This is homonomous metamerism, such as is present in the earthworm. (4) In the most specialized phyla of metameric animals, however, there is more importance given to the segments toward the anterior end (*i.e.*, there is heteronomous metamerism resulting in progressive cephalization), and this often results in the formation of a distinct head which bears important sense organs. Appendages develop first, both phylogenetically and ontogenetically,* as mere outgrowths or flaps from the body and may later become jointed or modified in various ways.

* Phylogeny is racial development; ontogeny is individual development.

CHAPTER XIV

PHYLUM PORIFERA—SPONGES

Porifera means "pore-bearers," and the sponges could not have been better named. The body of any sort of a sponge is full of little canals which open through minute apertures over the whole outside surface (Fig. 65). On the interior the canals connect with larger channels which

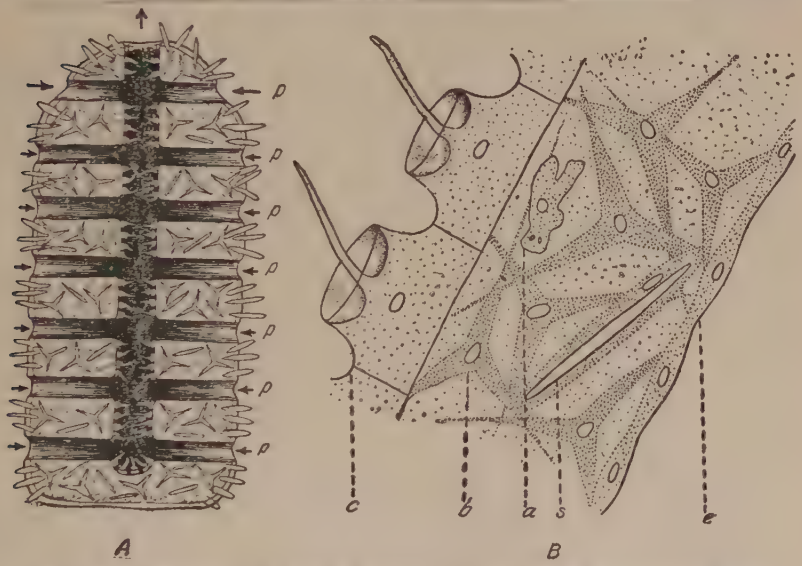


FIG. 65.—Structure of a simple sponge. A, half of an animal split lengthwise to show the central longitudinal canal and the lateral canals (*p*) leading into it. B, enlarged section of a sponge's body wall showing different types of cells; *a*, amœbocyte; *b*, undifferentiated cell; *c*, collared flagellate cell, or choanocyte; *e*, epidermis on outside of body; *s*, spicule within the cell that formed it.

lead again to the outside. Certain portions of the internal canals are lined with peculiar cells, the choanocytes, which each bear a flagellum and a flexible collar surrounding it (B, *c*). The flagella on all of these cells wave constantly and create currents in the canals. Most sponges have a

skeleton, which may be composed of separate spicules of lime or silica, or consist of a horny network. In their manner of growth sponges are much like plants, living attached to some object and varying their branches to suit the surroundings. The natural history of a simple representative of the Porifera will give some idea of the general activities of these peculiar metazoans.

A SIMPLE SPONGE

Self-maintenance.—A sponge obtains food from the water continually passing through its canals (Fig 65). Little plants and animals are sucked into the pores from the surrounding water, are drawn inside the collars of the choanocytes or engulfed by other cells as they pass through the canals. There is no digestive system, or digestive cavity, no mouth or anus. A cell lining a canal takes food into its cytoplasm much as an amœba does; digestion takes place only within the cells. The choanocytes and some other cells lining the canals are, therefore, the only ones able to feed, and they must pass on nourishment to the rest of the sponge body. There is no circulatory system to distribute food; transfer takes place through accidental spaces between cells and by gradually soaking from one cell into the next. Excretion occurs through exposed surfaces, and is greatly assisted by wandering amœboid cells which engulf waste particles and migrate outside the sponge's body with them.

Self-protection.—Sponges are not very palatable morsels for other animals, and hence have few enemies that seek to devour them. They are usually protected by the sharp spicules in all parts of their bodies. The spicules are accretions formed by cells which die after the work is completed (Fig. 65, B, *c*). They not only protect the body, but also help to support it.

Sponges grow attached and hence cannot migrate to new habitats if their surroundings become unfavorable. They

must be able to resist injurious conditions, or die. A large part of the body may disintegrate when the water is foul or when food fails; but if a few cells are left, they will grow into a complete new sponge, just as a tree may send up a shoot from its stump after being cut down. Sponges, then, usually have little power of resistance but possess remarkable ability to regenerate lost parts. Professor H. V. Wilson has recently succeeded in growing complete sponges from minute pieces which had been strained through a fine sieve. The bodies of fresh-water sponges disintegrate in the autumn, but certain groups of cells, the gemmules, form resistant coats about themselves, remain dormant until spring, and then grow into new sponges.

Race Preservation.—As has just been stated, sponges have remarkable powers of regeneration. Many species are even able to throw off parts of the body which grow into complete individuals. In a large sponge it is often impossible to determine how many individuals are present for the canals are interwoven and cross-connected inextricably. Sponges may be easily separated into parts without serious injury and different individuals are as readily fused together. All the methods of reproduction thus far described are strictly asexual—there is no fusion of sexual cells to form a zygote, no maturation, fertilization, or cleavage. Sexual reproduction does occur in sponges, however, and most individuals start in the beginning from a fertilized egg.

The ova and spermatozoa of sponges ripen during typical maturation stages, as described in the last chapter, and fertilization takes place as in other metazoans. Though the cleavage stages are somewhat peculiar, they are much like those in other many-celled animals. At this point, however, the resemblance between sponge development and that of other Metazoa ceases, for *no gastrula is formed.* In other words all metazoans, except sponges, pass through maturation, fertilization, cleavage, and gastrula stages; the sponges pass through the first three, but form no gastrula. This is taken to mean that all many-celled animals except

sponges are related, and that the Porifera arose independently from the Protozoa. The Metazoa are, therefore, divided into two groups (page 24): the Enterozoa, including most of the phyla; and the Parazoa, containing only the sponges.

These theoretical matters regarding classification are not to the point, however, and we will return to the development of the sponge. A ciliated larva is formed within a special cavity, or brood pouch, after cleavage inside the body of its parent. The larva when set free leaves its parent's body in the water currents and swims about actively until it finds some suitable place for attachment; then settles down, loses its ciliated covering, develops pores through the tissues, and grows into a mature sponge.

In its mature state a sponge is barely across the line between the Protozoa and the Metazoa. It has tissues, but that is about all that can be granted it! There is little or no correlation between the different parts of the body, and there are no organs. Each tissue does its work more or less automatically and is rather independent of others. The flagellated choanocytes beat continually until they die, and will always make currents if the canals are open. If some injurious substance is entering with the water, it can be excluded only by closing the openings, and such closure is brought about by the direct action of the substance on the little sphincters, or rings of muscular tissue, surrounding the openings. If a certain part of a sponge's body is cut, it may contract and adjacent pore openings may close, but there is no transmission of the disturbance to other parts of the body. The sponge is, therefore, a rather poorly organized community of tissues. Muscular and supporting tissues are present but there are no nerves, nor are there evidences of nervous transmission. This is an interesting fact from a psychological point of view for it indicates that the nervous system in animals generally has arisen after various effectors (muscles, glands, etc.), and has secondarily come to control them. A sponge has effectors (parts of the

body capable of doing work), but has no nervous mechanism to control them and they respond when stimulated directly. In more specialized animals the nervous system has more or less complete control of effectors—the receptors (eye, ear, etc.) receive stimuli and send impulses to the central nervous system, which in turn sets off appropriate effectors.

SPONGE FISHERY

The total value of the sponge fisheries of the world amounts to about $3,500,000 annually. In the year 1907 sponges were imported to the United States to the value of $488,426 and exports during the same year amounted to $144,354. In 1908, on the Florida fishing grounds alone, 622,489 pounds of sponges were captured and sold for $548,876. The growing importance of the sponge fisheries has led the federal government to make studies of the best methods of propagation and fishing.

It is possible to raise sponges from slips, like plants, and this has been made use of in a commercial way. Selected individuals of good quality are cut up and the pieces placed on the tips of sharp stakes attached to a frame. The frame is lowered to the bottom of the ocean, left for a year or two, and raised again. If all has gone well, the "slips" have grown to marketable size and are of good shape (Fig. 66). It is possible to graft fragments of fine sponges on the attached growing bases of other indviduals of poor quality. The two sponges fuse and a vigorous growth of the desirable portion is thus obtained.

Sponges are usually collected by hooking or diving. In the first method one man rows a boat and another uses a rake-like hook to tear the sponges from their attachments. In the second, divers go down and cut the sponges off the bottom by hand. Along the shores of the United States fishers usually wear diving suits, but in the Mediterranean and other seas they are more often nude. In some places dredges are used in capturing sponges, but they are un-

desirable because they destroy great numbers of young individuals. Sponges soon die on the deck of a vessel, and are allowed to rot for a day or two. They are then hung over the side of the ship or placed in "crawls," or cages, in the water alongshore to macerate until the flesh is very soft.

FIG. 66.—Showing sponges grown from "slips" on spikes set in cement blocks and left for a time on the bottom of the ocean. (*From Moore.*)

When thoroughly rotted, the sponges are beaten and squeezed under water. They are then strung in bunches and auctioned off to buyers on the wharves. In the packing houses the sponges are trimmed, cleaned, sorted according to size and quality, and sometimes bleached. They are then ready for the consumers.

CHAPTER XV

PHYLUM CŒLENTERATA; PHYLUM CTENOPHORA

The cœlenterates are all modified gastrulas which are radially symmetrical, and possess peculiar "stinging cells," or nematocysts. They are all aquatic, and most of them are marine, only a very few species, occurring in fresh water. Well-known examples of the phylum are polyps, such as corals and hydras, and the jellyfishes, or medusæ. In many species there is an alternation of generations—a polyp stage giving rise to a medusa, and it in turn to a polyp again. There are three classes: Hydrozoa, Scyphozoa, and Anthozoa.

CLASS 1. HYDROZOA

On account of the bush-like forms often assumed by the colonies of polyps when growing alongshore, the cœlenterates in this class were long known as "zoophytes" or "animal plants." A "bush" may bear hundreds or even thousands of little polyps at the tips of the branches, and all are connected through the twigs with the main stalk of the colony which is attached to some solid object. Though polyps are the most prevalent types of animals in this class, minute medusæ are usually produced at intervals. All medusæ are shaped more or less like an umbrella and those of the Hydrozoa are easily distinguished from others by the presence of a velum—a shelf-like structure projecting inward around the entire margin of the umbrella (Fig. 68, *v*). Along the Atlantic coast of the United States a little hydrozoan grows very commonly on docks, piles, and seaweeds. This is *Obelia geniculata* (Linnæus), a Colonial Hydroid, which may well serve as an example of

this class. This hydroid always grows as a branching colony (Fig. 67). All individuals are intimately associated with each other and the food taken by one animal may pass down the hollow stalk to nourish other members of the colony. Such coöperative activity between different

Fig. 67.—Obelia, a colonial hydrozoan. A, a small colony somewhat enlarged; B, portion of same greatly enlarged; *b*, medusa buds; *c*, cœnosarc, or soft flesh; *e*, old branch from which an individual has broken off; *g*, gonangium, or reproductive individual; *h*, a mature hydranth; or feeding individual; *j*, joints to permit bending of hydranth on its stem; *m*, young medusa swimming out of gonangium; *p*, perisarc; *y*, young hydranth.

individuals makes division of labor possible and in Obelia differentiation of functions has gone so far that some members of the colony carry on reproduction and cannot feed, others only feed and cannot reproduce. There are, then,

two kinds of individuals at the ends of the branches: feeding hydranths (*h*) and gonangia (*g*). Obelia is therefore an example of *polymorphism*, a condition in which a single species appears in more than one form.

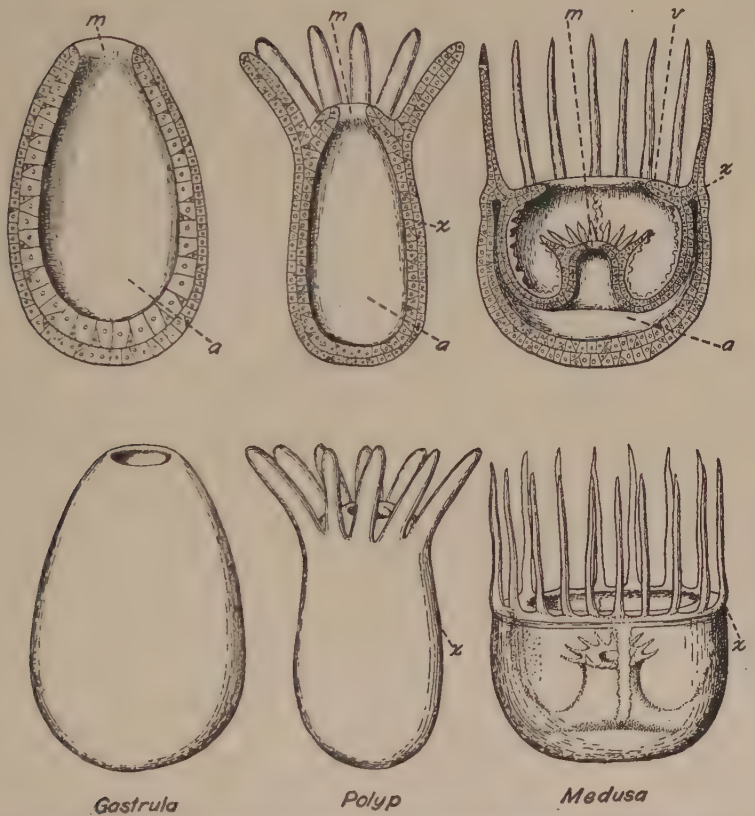


FIG. 68.—Indicating the fundamental structural similarity between gastrula, polyp, and medusa. The polyp is a gastrula with tentacles; the medusa is like a polyp that has grown upward around the tentacles in the region of *x*. *a*, archenteron, or primitive digestive cavity; *m*, mouth.

It has been said that all cœlenterates are modified gastrulas, and this will hold true for both hydranths and gonangia. In a hydranth a circlet of tentacles has grown about the gastrula's mouth, which is simply the original opening into the archenteron (Fig. 64, G). The gonangium

has developed no tentacles, but has little knobby buds along its sides. Both sorts of individuals have only two layers (ectoderm and entoderm) in the body wall. The hydranth is a polyp (Fig. 68) which differs but little from a gastrula, except for the connections it has with the other individuals in a colony.

Self-maintenance.—The Obelia hydranths are the only individuals in a colony capable of feeding. Each one catches little animals in its tentacles and pokes them through its mouth into the simple digestive cavity. There

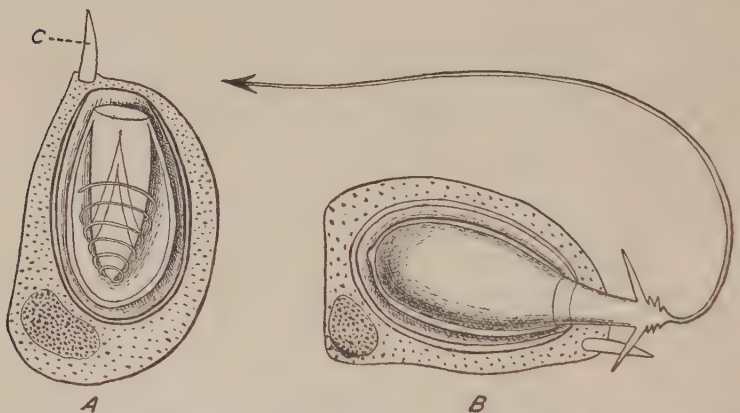


FIG. 69.—A cnidoblast, or cell containing a nematocyst. A, with nematocyst coiled; B, nematocyst discharged; *c*, cnidocil, or trigger.

is no opportunity to move about to look for food, hence Obelia always grows where there are currents and waves, so that food may be brought to it. If the animals captured are too lively and struggle about, they are stung by the nematocysts which cover the tentacles. The nematocysts of cœlenterates (Fig. 69) contain a poison which soon kills small animals, so that they can be swallowed without trouble.

After the food enters the enteron, or digestive cavity (Fig. 68, *a*) it is kept circulating by the movement of little flagella on certain cells in the epithelial lining (= ento-

derm). Other cells pour out secretions which soften and liquefy the food. If there are parts which cannot be digested they must be thrown out through the mouth for there is no other opening into the enteron, except the canal which leads down the stalk to connect with other individuals. The digested food is absorbed by the entoderm and part of it is there assimilated, but some soaks on through to nourish the ectoderm on the outside of the body. The layers of Obelia's body wall are so thin that there is no need for any separate circulatory or excretory systems; at any rate neither is present.

Self-protection.—An Obelia colony is invested over its outer surface by the peritheca, a tough horny secretion which forms a branched system of tubes and protects the soft tissues within. This exoskeleton has little openings at the tips of the branches so that the hydranths and gonangia may communicate with the exterior. Each hydranth is enclosed by a little cup, or hydrotheca (Fig. 67, *h*) into which it may withdraw when threatened with danger. The peritheca also keeps the delicate body from drying out, if it is by chance left exposed at low tide. If this protective covering were too rigid, it would be a burden and is therefore jointed (*j*) near the base of each branch so that movement is permitted.

The nematocysts (Fig. 69) help to protect Obelia from small creatures which might otherwise prey upon it, but some animals appear to be immune to their feeble stings. Certain crabs use Obelia and other hydroids as a favorite food. Some snails which have no shells not only devour the hydroids, but do so without discharging the nematocysts; and some species are even able to pass them out to their own backs where they use them "second-hand" to sting their enemies.

The attachment of Obelia to some solid object protects it from certain dangers. It cannot be swept up on the beach by storms and is never carried out to sea, but it thus sacrifices its ability to search about for food.

Race Preservation.—Obelia has a rather complicated life cycle because there is always an alternation of polyp and medusa. The polyp generation reproduces by asexual methods. It starts as one individual which produces a great number of others by budding; some remain attached to the colony and others are set free. The medusa produces zygotes which grow into young and vigorous polyps. Such an alternation of a generation which reproduces asexually by budding with another generation which produces new individuals by sexual methods is known as *metagenesis*.

Metagenesis in Obelia takes the following sequence (Fig. 71): The zygote (A) develops in the way described for a typical metazoan, passing through blastula and gastrula stages, and finally forms a ciliated larva (B) which swims about for a time, then attaches itself to some object along the shore. The larva is transformed into a little polyp (C), which soon starts to feed and forms a peritheca about itself. As it grows the polyp buds off hydranths and gonangia until a great branching colony is formed (D).

When the gonangia on a colony are mature, they are continually forming medusa buds (Fig. 67, *b*). These ripen into little medusæ (Fig. 71, E) which break loose and swim out through the opening at the end of the gonangium. A medusa swims by pulsating its umbrella, and is able to feed on small animals. It swims feebly, however, and is often swept a long way by ocean currents. Though some individuals may die before the ends of their journeys, such traveling is of benefit in general, for Obelia is thus able to become established in new localities. Each medusa is either a male or female. The females give off zygotes formed by the union of egg and sperm cells and the cycle thus begins again.

In metagenesis, then, as illustrated by Obelia, there is always an alternation of an asexual polyp generation with a sexual medusa generation. Polyps cannot form other polyps directly except by budding and medusæ must always produce germ cells which grow into polyps. At first

glance one generation is quite different in structure from the other, but if some details are ignored, striking similarities between polyp and medusa are apparent. Fig. 68 shows that a simple polyp may readily be transformed to a medusa by two changes—an additional ring of tentacles must grow out at *x*, and the part of the polyp bearing the mouth and tentacles will have to be pushed back into a cup formed by an outgrowth at the bases of the new set of tentacles.

If we compare Obelia with the sponge described in the last chapter, it is at once apparent that we are dealing with a more progressive animal. The sponge excels Obelia only in its great elaboration of tissues. Though a hydroid has its tissues rather poorly defined, it shows progress in other ways: there is a definite digestive cavity; the tentacles are *organs*, for they consist of different tissues which coöperate to capture food and poke it into the enteron. There is coördination between different parts of the body in a hydroid, whereas a sponge must have each of its tissues activated by a direct stimulus. If meat juice is squirted in the water near an Obelia, the tentacles wave toward the source of the extract and the mouth is also bent in the same direction. If the tip of a tentacle is injured the whole hydranth withdraws within the protection of the peritheca. A sponge is a rather loosely coördinated federation of tissues; a hydroid is a well-organized metazoan with a definite digestive cavity and simple organs.

Obelia may be looked upon as an average hydroid. Other representatives vary greatly in the degree to which polymorphism and metagenesis have been developed. The fresh-water Hydra (Fig. 68, Polyp) shows a very simple condition. It consists of a simple polyp which may at times form new individuals by budding and at other times give off eggs or spermatozoa. The zygotes grow into polyps and there is thus no metagenesis and no polymorphism. The Portuguese man-of-war, *Physalia* (Fig. 70), which floats in tropical seas, shows an extreme case of polymorphism.

In this hydroid there is a bladder which bears a colony of hydroids beneath and there are five kinds of individuals. The nematocysts of Physalia are very poisonous; bathers swimming against the trailing submarine batteries experience great pain.

FIG. 70.—The Portuguese man-o'-war. A, general view; B, sectional diagram to show different kinds of individuals in the colony; *e*, gasterozoid, or feeding individual; *f*, dactylozoid; *g*, dactylozoid with tentacle; *i*, female reproductive individual; *n*, male reproductive individual.

CLASS 2. SCYPHOZOA

In scyphozoans the medusa stage is always much more important than the polyp. The jellyfishes do not have a velum, and many of them are very large; *Cyanea capillata*, which occurs off the New England coast, attaining a diameter of six feet. The polyp of a scyphozoan is always small and inconspicuous. It forms medusæ by a peculiar type of budding known as strobilization, *i.e.*, constrictions are formed about the body so that it looks like a pile of saucers; the top "saucer" periodically breaks off and swims away as a young medusa (Fig. 71, D).

On account of their large size and great abundance in many parts of the ocean, scyphozoans have been much used for experimental work in zoology and physiology. One

group of experiments dealt with the control of the rhythmical pulsation of the umbrella. There are eight nerve centers around the margin of a jellyfish; these control the pulsa-

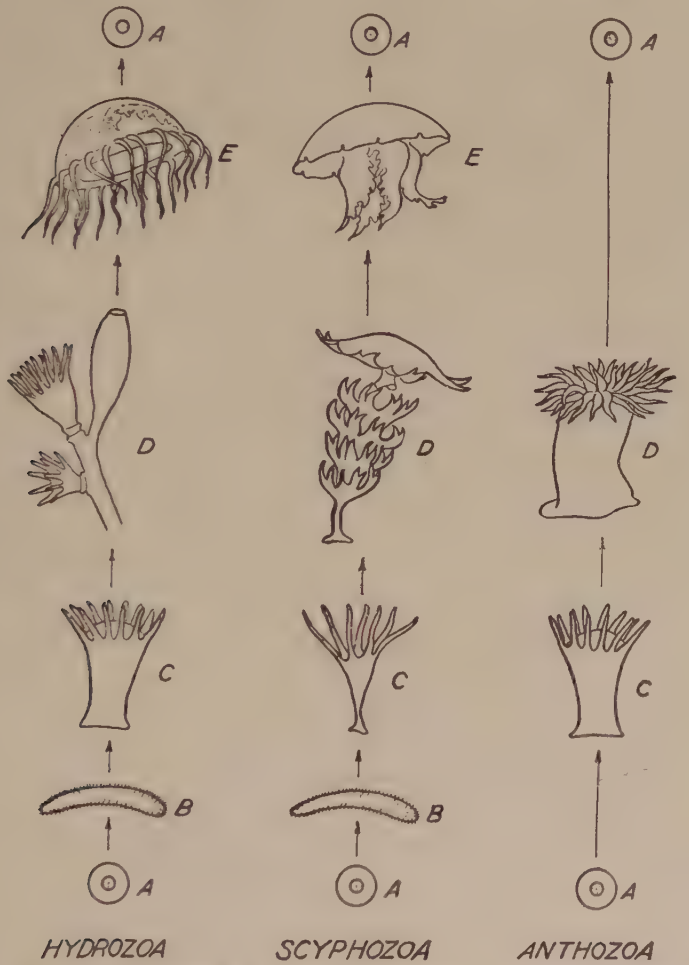


FIG. 71.—Life histories of typical cœlenterates. A, zygote; B, ciliated planula; C, young polyp; D, mature polyp; E, medusa. In the Hydrozoa all stages usually appear in a well developed condition; in the Scyphozoa the polyp is always small and unimportant; the Anthozoa never have a medusa stage.

tion and all are correlated so that the area dominated by each beats synchronously with other regions. If all but

one of the centers are removed the whole umbrella keeps on beating as before; if all the centers are removed, however, there is no more pulsation. The medusa therefore has a very wide margin of safety in case of injury.

CLASS 3. ANTHOZOA

The Anthozoa have no medusa stage, there is, in fact, no indication of metagenesis. The polyps produce eggs and spermatozoa which form zygotes, and these grow into polyps like their parents (Fig. 71, D). Anthozoan polyps are more complicated than those in any other group. There is a gullet leading from the mouth into the digestive cavity, which is divided up into small compartments by thin partitions.

The anemones are solitary polyps which form no skeleton whereas corals are colonial anthozoans. Corals live in large colonies, often showing great polymorphism, and secrete a skeleton of lime or other substances. Many islands and atolls have been formed entirely from the skeletons of corals during periods when the bottom of the ocean was slowly sinking.

GENERAL REMARKS ON CŒLENTERATES

When considered in relation to the Protozoa and Porifera, the phylum Cœlenterata is remarkable for several reasons. The following points should be particularly kept in mind: (1) though many Cœlenterata are very complicated in structure, none is much more than a modified gastrula; (2) though tissues are rather poorly developed in some, others have well-defined supporting, nervous and muscular tissues; (3) organs are present; (4) a definite cavity, the enteron, is used for digestion and it presents the simplest condition to be found in any of the Enterocœla (Fig. 18, page 24), having but one opening; (5) colony formation and polymorphism are common; (6) metagenesis, or alternation of a sexual and

an asexual generation, is here developed as it is nowhere else in the animal kingdom.

PHYLUM CTENOPHORA

The ctenophores, comb-jellies, or sea-walnuts (Fig. 72), are extremely transparent, jelly-like animals which swim at the surface of the ocean. They are often shaped like a walnut, as one of their names indicates, and have two retractile tentacles which trail behind as they swim. There

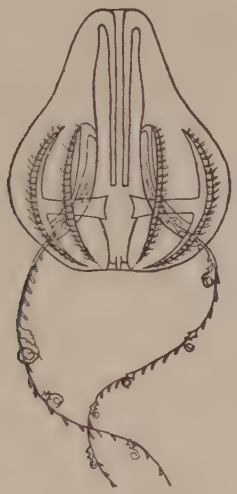


Fig. 72.—A ctenophore.

are eight rows of comb-like paddle plates which propel the body slowly through the water. Ctenophores show a slight superiority over cœlenterates in the structure of the digestive system by having one or more openings, which may serve as an anus, at the opposite end from the mouth. They are usually protected from enemies by their extreme transparency, which renders them practically invisible during the day. Many species are phosphorescent, and give off light when disturbed.

CHAPTER XVI

PHYLUM PLATYHELMIA

Flatworms are bilaterally symmetrical and usually have a broad leaf-like form. Some have a digestive cavity into which there is only one opening, the mouth; in tapeworms, however, no digestive system is present. There are three classes:

Class 1. Turbellaria; free living Platyhelmia with cilia on the outside of the body and a well-developed digestive system.

Class 2. Trematoda, or flukes; parasitic flatworms, with a tough cuticle on the outside of the body and no cilia.

Class 3. Cestoidea, or tapeworms, which are parasitic, have a cuticular covering, and lack any digestive system.

CLASS I. TURBELLARIA

Turbellarians are the only flatworms that are not parasitic. They live for the most part in quiet places among vegetation, both in the ocean and in fresh-water, and seek actively for small animals which are swallowed whole. The fresh-water planarians are probably the most familiar representatives, and the activities of one of these worms will be considered.

Planaria maculata Leidy

Self-maintenance.—This turbellarian (Fig. 73) frequents weedy ponds, springs, and the shores of lakes. It crawls about among aquatic plants looking for food. Locomotion is accomplished by the movement of cilia covering the outside of the body and is also greatly facilitated by the slime, which gives the worm a firm enough hold on solid objects so

that the body may be extended and contracted by muscular movements. A planarian crawls about until it encounters some little animal suitable for food. The proboscis is extended through the mouth (Fig. 73), wraps about the food, and is then drawn into the body. Though a planarian has a pair of simple eyes, they are not used to any extent in seeking or capturing food, but it does have the ability to recognize food through chemical substances given off in the water. If an injured animal is encountered which is bleeding slightly, it will be followed about persistently, but

FIG. 73.—Planarians. The individual at the left is in the act of swallowing a small crustacean. On the right is a planarian which has had its head cut off; the body has regenerated a new head, but the small fragment has formed a two-headed monster.

a sound and whole individual may not be noticed. Planaria's mouth is in a rather strange position, at the center of the ventral surface, but that situation gives good opportunity to stretch the proboscis out in any direction.

After food has been drawn into the body it passes down the proboscis, or pharynx, into the digestive cavity which has three chief branches—one leading forward to the anterior end of the body and two leading back on either side of the mouth to the opposite end. The three main canals have many small side pouches, and food is thus distributed in the digestive system to all parts of the body. It is,

therefore, unnecessary to have a separate circulatory system, and none is present. Planaria does have a very elaborate excretory system, however, which consists of a branching tube on either side of the body. The branches end in "flame cells;" so named because each is hollow and has a bunch of cilia within which resemble the flickering of a candle, when moving. The flame cells force waste products down the tubes and ultimately out of the body through two little pores on the dorsal surface.

Self-protection.—Planaria escapes most of its enemies by hiding. Its eyes are of value in enabling it to shun light and seek dark crevices, but the whole surface of the body is also sensitive and a planarian can respond nearly as well after the eyes have been removed.

If Planaria is captured and half eaten by some predaceous enemy, it is not a very serious matter, for either half of the body is able to regenerate what it may lack and after a time becomes a complete individual again. During such reconstruction no food is taken as a rule, but the body is reorganized and forms a complete new worm from the substance already within it; the size, of course, being smaller. Some species of planarians can regenerate a complete body from about one twenty-fifth of the original, but there is a definite limit and most species show polarity in their bodies. Polarity in this sense means that certain regions are specialized and can regenerate only particular parts. For example, if the head of Planaria is cut off just behind the eyes, the anterior piece will not grow a new body but grows another head and becomes a two-headed monster (Fig. 73). A small portion from the opposite end will likewise form a double-tailed individual. Such behavior shows that the two ends of the body are so specialized that they can only form parts like those they already possess.

Race Preservation.—Planaria takes advantage of its remarkable powers of regeneration to produce new individuals. A pair of eyes, a proboscis, and other necessary organs are often formed in the posterior half of body, which

then breaks away from the anterior portion. New individuals are thus produced by transverse fission.

Planaria also carries on reproduction by sexual processes involving the fusion of egg and sperm cells. Each individual is hermaphroditic and, therefore, has complete sets of both male and female organs (*i.e.*, testes, vasa deferentia, or sperm ducts, penis; and ovaries, oviducts, sperm receptacle, yolk glands, shell glands). Though a planarian might "fertilize" itself by injecting its own spermatozoa into its female reproductive system, it does not commonly do so, but obtains its supply of sperm from some other individual, and in turn gives its sperm to fertilize the other party concerned in the mating. The eggs laid by Planaria are of two types, but both have several yolk cells enclosed in the shell with the ovum. During the summer thin-shelled eggs are laid which develop quickly, but in the autumn thick-shelled "winter eggs" are produced which lie dormant until spring.

The cleavage and gastrula stages in Planaria's development are somewhat peculiar but there is general agreement with the stages usual in metazoans (Fig. 64). Though Planaria is like a gastrula in its retention of the single primitive opening into the enteron, it is specialized in many other respects. There is a large mass of mesoderm which consists mostly of muscles and loose parenchyma cells (Fig. 76); the systems of organs are much better organized and more elaborate than in cœlenterates, particularly the reproductive, excretory and nervous systems. Specialization toward better things than have been suggested in the structures of the sponges and cœlenterates are shown by Planaria (1) in the assumption of the bilateral type of symmetry, and (2) in cephalization. Most of the dominant and highly specialized animals on the earth are bilaterally symmetrical; in fact, radial symmetry may usually be taken as a sign of racial conservatism, or even of retrogression. Cephalization, or the placing of important organs at the anterior end, naturally follows the acquisition of bilateral symmetry. A jellyfish may move in any direction and

what little power it has of directing its attention must be divided between the eight or more marginal sense organs. A planarian has only one chief nerve center in the head; the eyes and other sense organs are localized at the anterior end. The jellyfish can perceive stimuli from different directions; the planarian always moves with a certain part of the body ahead and this part receives most of the stimuli from the outside world. Planaria is better able to devote its very limited powers of attention to one thing at a time because the chief perceiving and modifying organs are gathered together to some extent, and from a psychological point of view this is an important point. The ability to pay attention comes before the power to draw conclusions, or to reason. Though Planaria, on account of its bilateral symmetry and cephalization, is on the road which leads toward the higher types of mental development, it has made little progress. Its mental powers are at best extremely limited, and its activities consist largely of a few rather simple, and more or less stereotyped, reactions.

There are a number of different kinds of turbellarians. Some are much more complicated structurally than Planaria, and others are far simpler. The rhabdocœles usually have a straight unbranched digestive cavity; some even have no definite enteron and the food simply enters irregular spaces in the parenchyma after passing down the pharynx. The polyclads have many intestinal branches leading out from the pharynx. Planaria, like most freshwater turbellarians, belongs with the triclads because its enteron has three chief branches.

CLASS 2. TREMATODA

The trematodes are all parasitic flatworms with a cuticular covering and a rather simple enteron. They may be divided into two groups, according to habits. The ectoparasitic trematodes are monogenetic, that is, they live on the outside of one host. They have a simple life history, the adults laying eggs which hatch into small worms like

their parents. They are found for the most part on cold-blooded vertebrates, like fishes, mud-puppies, and frogs. The endoparasitic trematodes live in various internal organs (liver, lung, intestine, bladder, etc.) and are mostly digenetic —*i.e.*, must pass through two or more hosts to complete the life cycle.

Trematodes are rather common parasites in all sorts of animals, and there are several species which infect man. *Fasciola hepatica* is the well-known fluke found in the livers of sheep, cattle, men, etc. Its life history is shown in Fig. 74. The adult fluke (A) lives in the bile ducts of the liver

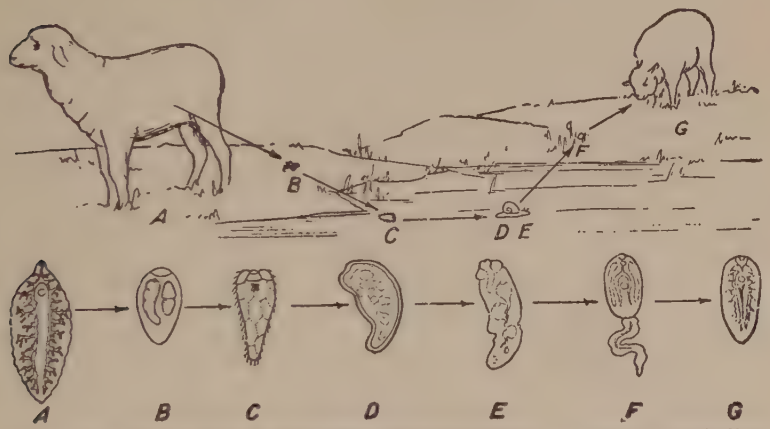


FIG. 74.—Life history of liver fluke, *Fasciola hepatica*. A, adult fluke in liver of sheep; B, eggs on ground washed into water; C, ciliated larva (miracidium) in water; D, sporocyst in snail; E, redia formed in sporocyst in snail; F, cercaria swims from snail to vegetation and encysts; G, cyst eaten by sheep and young fluke is set free.

and continually passes eggs (B) to the outside by way of the intestine. These eggs may lie about on the ground for some time without injury, but if they get into water soon hatch out little ciliated larvæ (C), which swim until they find a pond snail. The larvæ bore their way into the snail and then undergo complete reorganization to form sporocysts (D). These are big bladders which soon develop rediæ (E) in their interiors. Rediæ break out of sporocysts and, in the snail's liver, produce little tadpole-like

cercariæ (F). These leave the snail, swim to the shore, and form cysts on the vegetation. Sheep take in the young encysted flukes (G) through the mouth while feeding. Fasciola cannot become established in any district unless there are aquatic snails for the larval stages and warm-blooded vertebrates to harbor the adults. In favorable places, however, it often causes great losses to sheep raisers. In districts where human flukes are prevalent great care should be exercised in eating green vegetables.

CLASS 3. CESTOIDEA

All tapeworms are parasites, and have no enteron. Some are much like trematodes, except for the entire absence of any trace of a digestive system. The body of the simplest tapeworm is not segmented, and has a complete set of nervous, reproductive and excretory organs, but no digestive system. Most of the common tapeworms, however, have a long segmented body consisting of a scolex and a long chain of proglottids. The scolex has suckers, and often hooks also, for clinging to the wall of the intestine. The proglottids each contain a set of both male and female reproductive organs, thus constituting a complete hermaphroditic individual. The nervous and excretory systems, however, are more or less continuous through the scolex and the whole chain of proglottids. There has been some dispute as to whether a segmented adult tapeworm is to be considered as one or many individuals. The view now held by most zoologists is that the scolex is an asexual individual which buds off another kind of individuals, the proglottids. There is thus an alternation of generations between an asexual generation (scolex) and a sexual one (proglottid).

There are many species of tapeworms, all living as parasites in the alimentary canals of other animals. Nearly all must pass through two hosts before the life cycle is completed. The larval stages of the scolex usually occur in the flesh of herbivorous animals and the adult tapeworm is

found in the intestine of the animal which eats the herbivore. There are species which have their cycles between: pig and man, cow and man, fish and man, mealworm and rat, flea and dog, rabbit and wolf, etc.

The life cycle of the common beef tapeworm is shown in Fig. 75. An adult (A) in a man's intestine is continually giving off ripe proglottids (B) which pass out and shed eggs (C) upon the ground. A single proglottid may produce several thousand eggs, and the contamination of

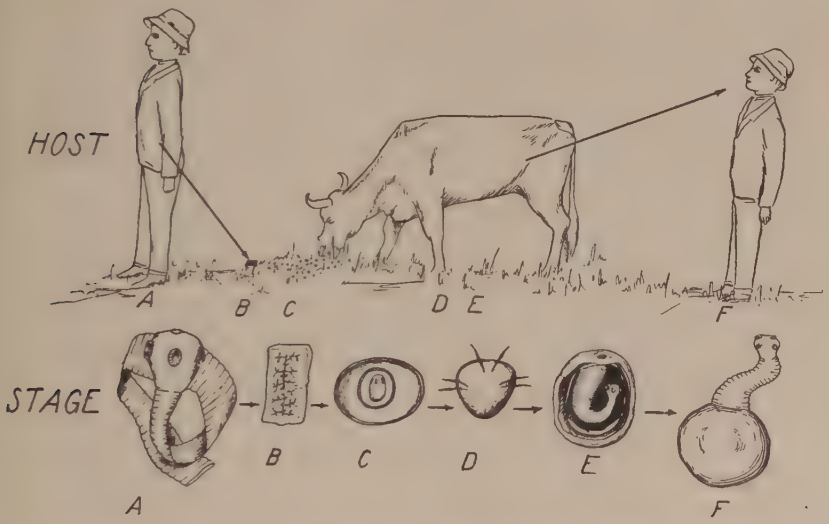


Fig. 75.—Life history of beef tapeworm. A, adult tapeworm in intestine of man; B, proglottid full of eggs on ground; C, eggs on ground; D, six-hooked larva (onchophore) set free and bores through tissues of cow; E, cysticercus, or bladderworm, in cow's flesh; F, young tapeworm in man.

the food of cattle is therefore easily accomplished. A ripe egg contains a little 6-hooked embryo (D) which is freed from the egg shell in the cow's intestine and at once bores out into the body. In the liver, or the muscles, it comes to rest and undergoes a complete reorganization. After three months a cysticercus, or bladder-worm (E), has developed and the cow's flesh may then infect man with tapeworms. The cysticercus is a little bladder with an in-

verted scolex on one side. If it gets into a man's intestine, the scolex is pushed out (F), fastens its suckers on the wall of the intestine and soon begins to bud off proglottids. About 1 per cent. of all the cattle slaughtered in the United States have tapeworm larvæ in their flesh, and there is another species which frequently infests pork. Any of these larvæ will be killed if meat is thoroughly cooked. A piece of meat if boiled should be cooked about fifteen minutes for each pound.

PHYLUM NEMERTINA

The nemerteans resemble the flatworms in their general form but are more specialized in many respects: an anus is present, the mouth is at the anterior end, there is a retractile finger-like proboscis above the mouth, a definite circulatory system is present for carrying blood. Some nemerteans are of large size, attaining a length of ninety feet. Most species live along the seashore, but a few are found in fresh water and on land.

CHAPTER XVII

PHYLUM NEMATOIDEA

The thread-worms, or round-worms, are slender and cylindrical in form. They have a tubular digestive system beginning with a mouth and opening at the opposite end through an anus. There is a body-cavity between the digestive tube and the body wall (Fig. 76). Different species of round-worms vary greatly in habits: some are free living, others are scavengers, and many live as parasites in plants or animals. There are three classes:

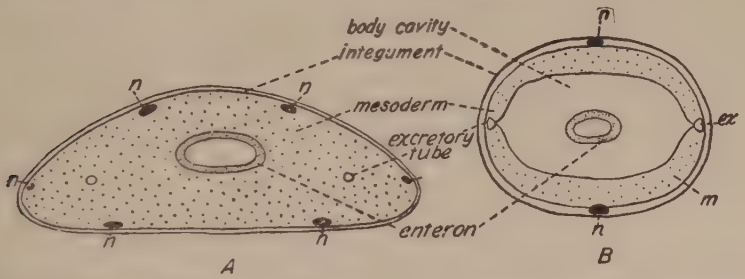


FIG. 76.—Cross-sections of a flatworm (A) and a round-worm (B) compared.

Class 1. Nematoda, round-worms with a well-developed digestive system and a rather simple life history.

Class 2. Gordiacea, horsehair worms. Parasitic Nematoidea with the digestive system often partly degenerate; life history very complex and requiring two or three hosts for its completion.

Class 3. Acanthocephala, hook-headed worms. Parasitic worms without a digestive system and with a proboscis at the anterior end which is armed with spines; in the life cycle there is usually an alternation between two hosts.

CLASS 1. NEMATODA

Most nematodes are very resistant to variations in the conditions of life, hence it is easy for them to live in all sorts

of odd situations. Many may become parasites if there is opportunity to do so, and a large number of species are permanently parasitic. As an example of the group a parasite of man will be considered.

Ascaris lumbricoides Linnæus

Self-maintenance.—Ascaris is a round-worm nearly a foot long which lives in the small intestine of man. It obtains its nourishment from the partly digested food of its host. As long as the man eats, the worm has a plentiful supply. There are three lobes at the anterior end which act as lips and poke food into the mouth. These are assisted by a muscular pharynx which exerts a sucking action and draws particles inside the body. Behind the pharynx the food traverses a straight intestine, where it is digested and absorbed. Undigested fragments pass out through the anus near the posterior end of the body. No special circulatory system is present, but the absorbed food passes through the wall of the intestine into the body-cavity (Fig. 76, B), where it is free to move from one end of the body to the other, and all parts are thus supplied. Excretions are collected by two tubes which run longitudinally on either side of the body (*ex*) and open together to the exterior through a small pore on the ventral side near the anterior end.

Self-protection.—Ascaris is in no danger from predatory enemies, for it rests safe inside some man. It is not digested by the strong secretions in the intestine, as the cuticle on the outside of its body is impervious to most chemicals and furnishes adequate protection. If the man containing an ascarid dies, the worm leaves the intestine and is often found, on *post-mortem* examination, in the stomach, throat or mouth. If the worm succeeds in escaping from the body, it is able to live for some time and may perhaps find entrance into another host. As a rule, however, Ascaris is in no danger if it once finds a host—but is able to pass its life in quiet and seclusion.

Race Preservation.—Ascaris is diœcious, that is, the sexes occur in separate individuals. Males are easily distinguished from females by their smaller size, by the coiling of the tail, and by the two little setæ which project just in front of the anal opening (Fig. 77). A female has a pair of long tubular ovaries which swing freely in the body-cavity and occupy a large part of its space. The ends of the tubes are enlarged to form a pair of uteri in which the eggs develop to some extent before passing from the body. The males have a single tubular testis which opens through the anus.

The eggs are fertilized far up in the ovarian tubules and pass down into the uteri where they have the shell added.

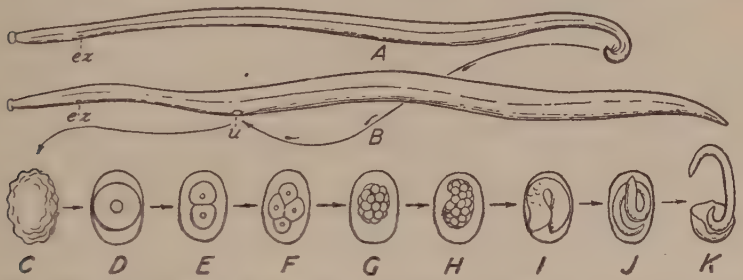


Fig. 77.—Life History of Ascaris. A, male; B, female; *ex*, excretory pore; *u*, female genital aperture; C, zygote; D, zygote without covering; E-H, cleavage stages; I, J, embryos; K, young Ascaris emerging from egg shell.

A female Ascaris is continually laying eggs, producing as many as 15,000 in a day. A large number of reproductive products is commonly associated with parasitic life and is necessary because the chances of finding a favorable place for development are small. This is, however, the only respect in which Ascaris shows adaptation to parasitism. The eggs pass out of the host and develop into larvæ in moist earth (Fig. 77, C-K) but do not hatch unless they get into a man (K). They cannot infect until they have been upon the ground thirty to forty days, and then are introduced into the human body on polluted vegetables, in water, or from soiled hands. After gaining entrance the worm hatches, becomes mature, and begins to lay eggs in about a

month. Recent investigations indicate that Ascaris may perhaps pass through larval stages in rats or mice before entering man.

Comparing Ascaris with a flatworm, it shows two great structural advances—a body-cavity and an anus. The flatworm must ingest and egest through a single opening; the round-worm has a much more convenient arrangement with an entrance for food and an exit for fæces. The body cavity is not a true cœlom, like that in the earthworm (Figs. 16, 89) and other animals, but is sufficiently developed to make the general structure of Ascaris' body a tube-within-a-tube, as described in Chapter II. It is simply a space between the muscles of the body wall (Fig. 76, B, *m*) and the digestive tube. This space is a great convenience, for it allows fluids to flow readily from one part of the body to another without having to pass from cell to cell, as is the case in sponges, cœlenterates, and also to some extent in flatworms.

OTHER NEMATODES

An Ascaris living in a man usually causes no very serious trouble, but sometimes one will crawl up the bile ducts into the liver and give rise to an abscess, or lodge in the appendix and induce appendicitis. Some other round-worms which live in man are much more injurious. The hook-worm, *Necator americanus*, is prevalent throughout the southeastern United States, where it was probably introduced by slaves brought from Africa. It gnaws the inner wall of the intestine and secretes toxins which impoverish the blood and thus weaken the body. The hook-worm has a peculiar life history—the adults lay eggs in the intestine; the eggs hatch into larvæ which live for a time in excrement or in the soil, and when grown enter man by boring through the skin; they then get into the blood and finally gain entrance to the alimentary canal by way of the lungs, trachea, and larynx. Persons with a heavy hook-worm infection may be abnormal in many ways: stunted and weak;

beard poorly developed; perverted appetite for clay, dirt, etc.; dropsical condition, and other peculiarities. The Rockefeller Sanitary Commission has agents throughout the southern states who are trying to better conditions among the poorer people by treatment and by instruction as to proper methods of living. In many districts the shiftlessness of the population is largely due to the prevalence of hook-worm. Ninety per cent. of the people in some counties in Louisiana have this parasite.

Another very injurious round-worm is trichina, *Trichinella spiralis*, which lives in rats, hogs, men, and a few other animals. This parasite may be acquired only by eating flesh containing the encysted larvæ, but if meat is thoroughly cooked there is no danger of infection. Other important human parasites are the pin-worm and the whip-worm, which live in the intestine; and the filaria worms which inhabit the blood and lymph vessels. The latter cause a horrible disease known as elephantiasis, in which the legs and other parts of the human body become greatly enlarged. They occur only in tropical countries, and are transmitted by the bites of certain mosquitoes. There are many round-worms which cause diseases in animals and plants. *Tylenchus tritici* is an important plant parasite which produces gall-like growths on the roots of tomatoes and other plants.

CLASS 2. GORDIACEA

These worms (Fig. 78, A) are commonly known as horsehairs, horsehair worms, and horsehair snakes, on account of their hair-like form, and there is a belief among ignorant persons that horsehairs will turn into worms if kept in water. They are often very numerous along the shores of ponds and streams during their breeding season. At such times they wrap about each other in great bunches, forming veritable "Gordian knots" (whence the name of the class). Sometimes the adult worms get into man and live for a time as parasites.

Most Gordiacea spend the greater part of their lives as parasites in insects and often have very complicated life cycles. *Parachordodes tolosanus* has two larval stages: the first enters the aquatic larva of the orl-fly and lives through the winter; the second develops in a beetle which has eaten an adult orl-fly and passes another winter in the beetle. The adult lives in the water, as a parasite in man, or in some other animal.

CLASS 3. ACANTHOCEPHALA

The hook-headed worms (Fig. 78, B) are parasitic in fishes and other vertebrates, sometimes even in man. They

FIG. 78.—A, a horsehair worm, *Gordius;* B, a hook-headed worm (Acanthocephala).

have no digestive system but live attached to the wall of the intestine like a tapeworm. At the anterior end there is a protrusible proboscis which is armed with hooks and serves as an organ of attachment.

The development of acanthocephalans requires an alternation of hosts; the larva usually living in some insect, crustacean or vertebrate, and the adult in a vertebrate. The common June-bug, or June-beetle, carries the larva of *Gigantorhynchus hirudinaceus.* This parasite lives as an adult worm in the intestines of pigs, which become infected by eating beetles. In South Russia, where beetles are eaten raw, the worm is said to occur in man.

PHYLUM ROTIFERA

On account of the ciliated discs at the anterior end, rotifers (Fig. 79), were called "wheel-animalcules" by the zoologists who first studied them. When the cilia are

in motion they make the discs appear like rotating wheels —hence the name Rotifera (*fero*, I carry; *rota*, a wheel).

These animals are remarkable for their small size. Though they are well-developed metazoans with more specialized systems of organs than round-worms, they are usually no larger than single-celled animals, and most species can barely be seen with the naked eye. The mouth is situated between the trochal (ciliated) discs where it receives the food brought in the vortex created by the cilia. The food is ground in a mastax, or chewing stomach, which is

Fig. 79.—Rotifera.

provided with chitinous teeth. Behind the mastax there is a glandular stomach where digestion takes place, and the residue passes out through an anus on the dorsal side near the posterior end. The excretory system consists of a pair of branched tubules and a contractile bladder which empties through the anus. Rotifers have a body cavity, but it is not a true cœlom.

Rotifers are of separate sexes. The males are smaller than the females and are often degenerate—sometimes the digestive system is entirely lacking. The females produce two kinds of eggs: summer and winter. The summer eggs are parthenogenetic, have thin shells, and are of two sizes—the larger producing females and the smaller males. The

winter eggs, which are fertilized, have thick shells, are able to pass through a long resting period before hatching, and always develop into females.

The ordinary life of a rotifer is about six weeks but certain species, if dried slowly, will form gelatinous cysts and are then able to live in a dormant condition for a long time. When encysted, rotifers can stand great extremes of temperature without being killed.

Rotifers in their adult condition resemble a trochophore larva, which occurs in the development of certain molluscs, annelids, and in some other animals. This has led some zoologists to believe that rotifers are closely related to the ancestral forms of molluscs, worms, etc., but such relationship cannot be very close because the rotifers are a very specialized group, and would not, therefore, give rise to new lines of descent.

PHYLUM BRACHIOPODA

Brachiopods are marine animals having a calcareous bivalve shell and usually a short stalk which fastens them to the ocean bottom. They resemble clams somewhat in appearance but have no close relationship. The valves of a brachiopod's shell are dorsal and ventral, instead of right and left as in clams. The body is very small and the space within the shell is mostly filled by two ciliated arms which create currents for procuring food. Within the body there is a spacious cœlom, a stomach, heart, and digestive gland. An anus may be present or absent. All the structures mentioned show some resemblance to those of other worm-like forms, but are modified to suit a sessile life.

Brachiopods lead a sluggish existence at the bottom of the ocean, and have done so since the earliest geological times. Most of the shells which appear as fossils are the remains of these animals. The abundance of such deposits indicates the past dominance of the Brachiopoda, which at one time shared the earth with trilobites and archaic

molluscs—when there were no vertebrates to interfere with their simple activities.

PHYLUM BRYOZOA

Bryozoans, or "moss-animals" are usually colonial in habit and resemble hydroids in general appearance. Most species are marine but a few occur in fresh water. They appear as encrustations, or as little plant-like growths, attached to objects in the water. The individuals of a colony are called zooids. Each has a circle of tentacles about the mouth and shows a superficial radial symmetry, as is the case in many attached animals. The digestive tube is U-shaped and the anus therefore opens near the mouth. Despite their superficial resemblance to hydroids, bryozoans are more nearly related to the worms. They, like the brachiopods, are peculiar on account of their sedentary existence.

CHAPTER XVIII

PHYLUM ECHINODERMATA

The name of this phylum means "spiny skin," and is fitting for most representatives. Echinoderms are radially symmetrical, and usually have five antimeres; an anus is present in some but non-functional or absent in others; the cœlom is large and well developed. The distinctive feature of echinoderm structure is the ambulacral, or water-vascular, system which serves primarily for locomotion. There are five classes: (1) Asteroidea, starfishes; (2) Ophiuroidea, brittle-stars, or snake-stars; (3) Echinoidea, sea-urchins; (4) Holothuroidea, sea-cucumbers; (5) Crinoidea, stone-lilies.

CLASS 1. ASTEROIDEA

The starfishes all have the chief axis short, and the distance from the mouth to the opposite pole of the body is accordingly abbreviated. The central portion of the body, or disc, is not sharply set off from the arms, but grades rather gradually into them. Most starfishes have five arms, or rays, but there are several species which have more; the number sometimes reaching as high as forty. The common starfish along the seashore on the Atlantic coast of the United States is *Asterias forbesi* (Desor) Verrill, and it will be discussed in detail as an example of the class.

THE STARFISH

Self-maintenance.—Asterias (Fig. 80) moves about by means of the tube-feet, of which there are four rows extending from a longitudinal groove along the underside of each arm. A tube-foot has an adhesive disc at its tip and is con-

nected with a little reservoir, or ampulla, within the body wall. Muscles in the wall of the tube-foot make it possible to move the organ about, like an elephant's trunk, and the adhesive disc may thus be put down in a particular spot. When the tube-foot is extended the reservoir connected with its base is small, but if it contracts, the reservoir is distended by the water which is forced into the body. Water first enters the starfishes' water-vascular system through the madreporic plate, or "sieve plate," passes through a straight stone canal to a ring canal around the mouth, and from this a radial vessel which supplies the

FIG. 80.—Starfishes. A, eating an oyster; B, an individual which has lost four rays and is growing them anew; C, crawling by using the tube-feet.

tube-feet runs down the under side of each arm. The broad spread of the body and the great number of tube-feet enable starfishes to walk over soft mud, and the adhesive discs permit them to climb up vertical surfaces with ease. Though able to move but slowly, starfishes are well equipped to seek for food.

A starfish can tell when substances are present in the water which indicate that food is near. If an individual is

resting quietly in a current and clam juice is added to the water, it will become restless and move about. If a screen is placed so that the starfish cannot reach the food, it will move as near as possible and try to pass by the obstruction.

On account of its taste for molluscs, the starfish is one of the worst enemies of the oyster and clam fishermen. The method by which a starfish opens an oyster was long a matter of speculation, erroneous observation, and dispute. One man thought an acid was secreted which dissolved the shell; another asserted that the starfish took the oyster by surprise and stuck its arm in the gaping shell before it could be closed; other equally fantastic theories had advocates. The starfish opens oysters by tiring them out. The tube-feet are attached on either side of the shell and a steady pull is thus brought to bear on opposite sides (Fig. 80, A). The oyster has two strong muscles to keep the shell closed, but these finally become tired and the starfish then gains access to the food inside.

A starfish has a most direct route from food to stomach. After an oyster has been opened, soft folds of the stomach are protruded through the mouth and wrapped about the parts suitable for food. Digestion and absorption take place inside the oyster's shell and outside the starfish's body! There is one disadvantage connected with this method of feeding—large amounts of digestive fluids are wasted. A starfish therefore has enormous digestive glands which fill most of the space within the body. The anus in most starfishes is not functional, and, indeed, it has small chance to be, for waste seldom enters the short intestine.

About the big baggy stomach there is a spacious cœlom and in this cavity the food may pass readily to all parts of the body. A set of tubes (hæmocœl) also carries fluid to certain obscure regions, but the starfish has little need of a separate circulatory system. Respiration takes place through the tube-feet and branchiæ. The former are admirably fitted for respiratory purposes; the reservoirs, or ampullæ, being in the cœlomic cavity, and the external por-

tions with their thin walls swinging about freely in the water. The branchiæ are minute, finger-like organs which are scattered plentifully over the whole upper (aboral) surface of the starfish. They are hollow and connect directly with the cœlom. Cilia keep currents passing in and out of the branchiæ, and the cœlomic fluid is thus aerated through the thin membranes exposed to the sea water. Asterias has no special means of excretion, except little amœboid cells which wander about in the tissues engulfing waste products. These finally migrate outside the body with their loads.

Self-protection.—Asterias is protected from most predaceous animals by the hard, spiny skeleton. When left stranded at low tide, however, its watery body readily dries up. A starfish crawls boldly over the rocks at high tide, but creeps into crevices and hides when the ocean ebbs. There is a simple eye at the tip of each ray and the whole surface of the body is more or less sensitive to light; so Asterias can tell when it is in light or shadow, and is able to crawl toward dark spaces.

A starfish moves very slowly and the body gathers many particles of dirt which fall from above. Such accumulations are continually swept to the edge of the body and off by the cilia which cover the soft parts between the spines. There are many very small animals in the ocean which might gnaw the branchiæ and the flesh of the starfish if it were not for the presence of little seizing organs, the pedicellariæ, which are to be found around the bases of the spines. Each pedicellaria consists of a short stalk surmounted by a pair of calcareous pinchers. If a small animal starts to walk over the starfish, it is seized and held immobile until it dies (Fig. 80, C). The pedicellariæ are rather independent in reacting and will often pull against each other. They grasp anything that moves and hold on until they are jerked loose from the body, or until the thing they hold ceases to move. Through their activities the

soft parts of the body are shielded from small predaceous animals.

If a starfish meets with an accident and has one of its arms hurt, the injured appendage is cast off near its base and, after a time, a new one grows out. The body may be cut in two and each of the parts can regenerate what it lacks. By careful experiments it has been found that *Asterias forbesi* is able to form a complete body if left with the disc and one arm (Fig. 80, B). Professor Mead kept a separate arm alive for three months, but it did not regenerate anything, although it was apparently in good condition and crept about actively. Some years ago starfishes were commonly dredged up, cut in two, and thrown back into the

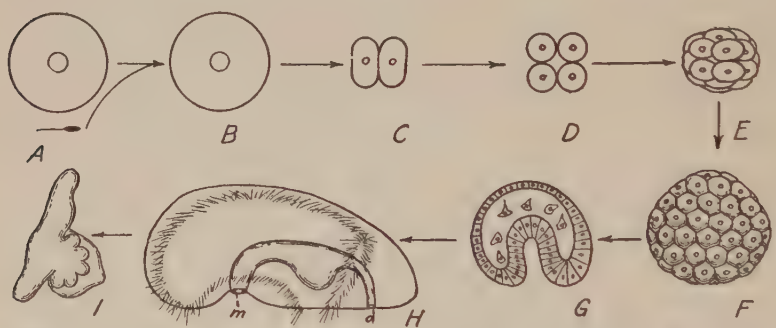


FIG. 81.—Development of starfish. A, egg and sperm cells; B, zygote; C–F, cleavage stages; F, morula; G, section through gastrula stage; H, ciliated bilaterally symmetrical larva; *a*, anus; *m*, mouth; I, young starfish growing out from side of bilaterally symmetrical larva.

ocean. The oyster fisherman supposed they were killed by such treatment, but it of course only increased the number of the pests.

Race Preservation.—Starfishes are diœcious animals and both the males and females shed their ripe sexual cells into the ocean. The sperm cells swim to the ova, fertilize them, and development passes through the stages characteristic of all metazoans (Fig. 81, A-G). After gastrulation (G) a bilaterally symmetrical larva is formed, which is known as a brachiolaria (H). It has a mouth (*m*), digestive tube,

anus (*a*), and cœlom. After swimming about for a day or two the brachiolaria attaches itself to a bit of seaweed and five little arms grow out on one side, thus beginning the development of the radially symmetrical starfish (I). Most of the brachiolaria collapses and in part disintegrates; the young starfish soon starts out to hunt clams and oysters. The growth of a starfish depends upon the amount of food it is able to secure. Mead separated two which changed from larvæ at the same time and kept them under observation for thirty-nine days. One was fed, the other received no food, and at the end of the period the former was fifty times as large as the latter. A starfish may become mature in less than a year; and, as each female lays several thousands of eggs, the rate of increase is rapid.

Although Asterias, like most starfishes, uses only sexual methods of reproduction to produce new individuals, there are some species which are able to multiply asexually. Linckia, for example, breaks off the tips of its arms and such fragments grow into complete new individuals.

GENERAL REMARKS ON STARFISHES

The starfish is a fairly successful representative of a somewhat unprogressive biological principle. It has greatly elaborated the radial type of symmetry, and represents, with other echinoderms, the highest degree of specialization along such lines. That the radial arrangement of body parts has some things in its favor cannot be disputed. It is certainly advantageous to be able to move with equal facility in any direction. It is desirable to be able to take food or receive notice of danger on any side of the body.

But usually the disadvantages more than compensate for the favorable features associated with radial symmetry. As was pointed out in connection with the cœlenterates, it is hard for a radially symmetrical animal to correlate its abilities for a particular end. A starfish has five arms

bearing five equally important sets of sense organs (eyes, tactile tentacles, etc.) and what little power of attention it has must vacillate between these or be continually divided. This is important because the development of higher psychical processes (memory, power of attention, reason, etc., as they appear in animals with well-centralized nervous systems) depends upon seriously attending to one thing at a time.

The behavior of a starfish is largely made up of more or less automatic "reflexes." If an individual is turned with its mouth uppermost, it slowly pulls itself over again, by using the tube-feet. Observers have noticed that various individuals may have different methods of righting themselves—that is, they have different "habits" of doing the same sort of work, and, therefore, show some individuality. Professor Jennings induced starfishes to forsake their usual methods of turning over, and taught them new ways. For example, a certain individual always began to turn with a particular arm, and when prevented from using that, learned to begin with another. Such lessons are very simple, but they show the limits of the starfish's "mind."

A starfish has its nervous system separated into three divisions; all essentially alike in structure. There are five nerves running longitudinally in each of the arms, and these are connected in the disc. Two divisions are near the oral surface, and the third lies in the aboral body wall. If the central connections are cut, the arms no longer work together, but each can still carry on its own activities. If an individual in which the connecting nerves have been severed is turned over, each of its arms tries to get back by itself. So far as its psychology is concerned, a starfish consists of five centers, or individuals, which usually work in harmony through the influence of the central connections.

The behavior made necessary by radial symmetry has, then, made the starfish unprogressive, and generally diffuse psychologically. And, if we look at the starfishes' ancestral tree, there is evidence that there has been retro-

gression. The embryological evidence (Fig. 81) indicates, according to the Law of Biogenesis, that starfishes were once free swimming bilaterally symmetrical animals (Fig. 81, H), with all the possibilities that go with that type of bodily arrangement, and that they gave up certain possibilities to become radially symmetrical and unprogressive. It is believed that this change came about because echinoderms at one time in their racial history took up a sessile mode of life and grew attached to the ocean bottom. It is desirable for an attached animal to be able to receive stimuli and capture food from as many directions as possible, hence the assumption of radial symmetry. But echinoderms, as a race, made a serious mistake when in the course of evolution they came to an attached mode of existence, for no sessile animal can progress very far. There are now some points of actual degeneracy. For example, the anus of the larva is functional (and was probably so in the ancestral types), but in many adult echinoderms is not used or is absent. In modern times there have been evolutionary attempts to correct early racial errors: most echinoderms, like the starfish, have taken up a free-living existence; some sea-urchins and sea-cucumbers have even become bilaterally symmetrical as adults (Fig. 82, B, F).

CLASS 2. OPHIUROIDEA

The brittle-stars, or snake-stars (Fig. 82, C) are very active, being able to bend the solid arms readily and thus swim about. They feed mostly on minute organisms which they scrape from marine plants with their feet. No anus is present.

On account of their activity, ophiuroids have been much used for experimental work. Attempts to teach them simple lessons have met with little success. In one series of experiments a rubber tube was slipped over one of an ophiuroid's arms, and behavior in attempting to remove it observed. There was "neither a decrease in the amount

of time taken to solve the problem, nor an increase in the frequency of movements best fitted to solve it," hence no learning.

Another line of experimental work related to the regeneration of lost parts. Ophiuroids readily break off pieces of their arms (whence the name, brittle-star) and many species commonly practise autotomy to escape from enemies. If an arm is grasped, it is thrown off and left to wriggle in the claws of the aggressor, while the ophiuroid escapes. Missing parts are readily regenerated and this

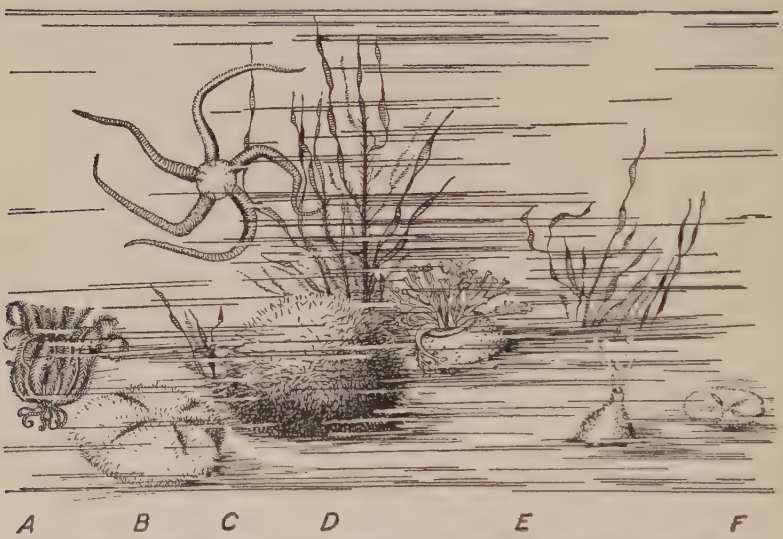


FIG. 82.—Echinodermata. A, crinoid; B, heart urchin; C, brittle star; D, regular sea urchin; E, sea cucumber buried in mud; F, cake urchin, or "sand dollar."

was made the basis for experimental work. One investigator maintained that the rate of regeneration was proportional to the degree of injury (*i.e.*, the more cut off, the faster the growth to replace the lost part), but further experiments showed that such a ratio would not hold absolutely.

CLASS 3. ECHINOIDEA

The sea-urchins differ from all other echinoderms in possessing (1) an immovable calcareous test, which is

usually more or less obscured by tube feet and spines, and (2) by the presence of a complicated system of calcareous ossicles which make up a chewing apparatus known as "Aristotle's lantern." Sea-urchins are globular, discoidal, or heart-shaped, and at first glance have little in common with the starfish, but, if one could take a starfish and bend the arms upward so that their ends came together and then fuse the sides, he would have made a sea-urchin. The calcareous tests of sea-urchins make respiration difficult and many species have therefore developed little brush-like gills about the mouth.

The cake-urchins and heart-urchins have the same general plan of structure as the "regular" sea-urchins, but have secondarily assumed bilateral symmetry. The cake-urchins, or sand dollars (Fig. 82, F), have the anus at one side (instead of at the pole opposite the mouth as in regular forms), and are very flat, so that they may move about on a soft bottom without sinking in. The heart-urchins have the mouth at one side and the anal opening at the other (B).

CLASS 4. HOLOTHUROIDEA

In the sea-cucumbers (Fig. 82, E) the calcareous exoskeleton, so characteristic of other echinoderms, is extremely degenerate, being reduced to little spicules which are embedded in the leathery skin. The chief axis is long, so that the body is worm-like. There is a ring of tentacles for feeding about the mouth. Respiration usually takes place through the anus; water being pumped by muscular action into two great respiratory trees, which branch out among the internal organs and fill up a large part of the space within the body.

Sea-cucumbers show remarkable instances of autotomy, or the casting off of parts of the body. One species, if removed from the sand in which it is accustomed to burrow, will break off pieces from its posterior end until only a twentieth of the original body remains. Another species when

placed in stagnant water, will throw out almost all of its internal organs (entire alimentary canal, most of the nervous and water-vascular systems), in fact, everything except the body wall and the respiratory tree. Certain tropical species when taken in the hands will turn into a slippery mass of slime which cannot be held. Many of these sea-cucumbers can, however, if conditions become favorable, regenerate all their missing parts in a short time.

CLASS 5. CRINOIDEA

The crinoids, or stone-lilies (Fig. 82, A), live for the most part at considerable depths in the ocean. They have five branched arms which are covered with little tentacle-like tube-feet. All crinoids are attached by the aboral pole when young, but some species break loose from the stalk when mature and swim about by waving their arms. The permanently stalked species often attain a great length, some measuring thirty or forty feet. Stone-lilies flourished in great numbers during past geological ages, and limestone deposits are often filled with their remains, the most common objects being little calcareous discs from the stalks.

CHAPTER XIX

PHYLUM ANNELIDA

The annelids are more completely metameric than the animals in any other phylum. The flatworms and nematodes do not have any indication of segmentation in their bodies, the rotifers are only imperfectly segmented, but the annelids are always made up of a chain of very similar parts. The phyla which rank above the annelids in structural complexity have the metamerism obscured by the outgrowth of the limbs and other appendages (Arthropoda, Chordata), or lack any trace of segmentation (Mollusca). This phylum therefore shows metamerism as it appears nowhere else in the animal kingdom. As a rule the cœlom of annelids is large and well developed; the body is therefore of the tube-within-a-tube type (Fig. 16). The alimentary canal possesses two openings. Annelids live in the ocean, in fresh water, and on land; some are even parasitic upon other animals. There are two important classes and one or two of less general interest, which will not be considered.

Class 1. Chætopoda. Annelids with setæ, or bristles, along the sides of the body.

Class 2. Hirudinea. Without setæ, but with suckers at either end of the body.

CLASS CHÆTOPODA

The chætopods (*chaite*, bristle; *pous*, foot) are abundant in most parts of the earth and are easily recognized by the setæ along the sides of the body. Sometimes the setæ protrude in great brush-like tufts from each metamere, in other instances they are small and almost completely buried

in the body wall. They usually take the form of stiff horny bristles which serve for locomotion. The earthworms are the most familiar representatives of the class, and one of the commoner species will therefore be considered as an example.

THE EARTHWORM, *Lumbricus terrestris* Savigny

This is the large earthworm found burrowing in humus soil throughout the northeastern United States (Fig. 83). It sometimes reaches a length of ten or twelve inches, and is most often seen above ground after rains.

Self-maintenance.—Lumbricus eats its way through the ground and thus obtains considerable food from the organic matter present. Most of the material excavated passes

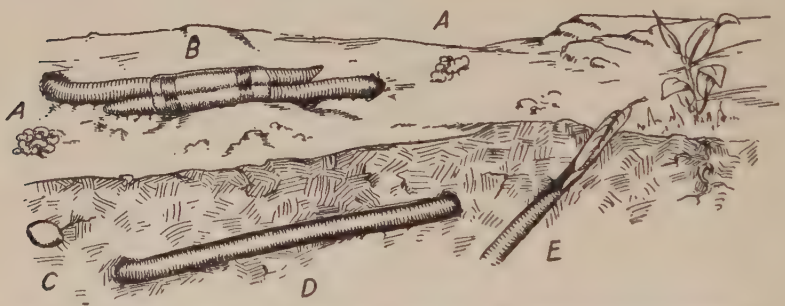


FIG. 83.—Earthworms. A, castings; B, mating; C, egg cocoon in ground; D, crawling in burrow; E, pulling a leaf into burrow.

through the alimentary canal and is voided into the burrow behind the worm or taken to the surface at night and left as a pile of castings (Fig. 83, A). The method by which an earthworm moves through its burrow is of interest. The setæ and two muscle layers are the chief agents in locomotion. If an earthworm is at rest and begins to move forward the sequence of events will be somewhat as follows: the setæ at the posterior end of the body are protruded and take firm hold on the sides of the burrow, then the circular muscles (running around the body) contract to make the body longer, and as the posterior portion is anchored, the

front end then moves forward. The setæ at the front end are next extended as those of the posterior end are withdrawn and the longitudinal muscles by contracting pull the body forward. Progress is continued by repeating such activities.

Though the earthworm is an indiscriminate feeder, it is not without a discriminating sense of taste. At night leaves and other parts of plants are pulled down into the burrows (E), to be eaten later. If foods such as cabbage, onion, and meat are placed on the surface of the ground where worms are abundant and left over night, it will be found that marked preferences are shown. Usually the meat will be eaten first, then the cabbage, and finally the onion. Hurwitz has recently shown that the chemical sense in the earthworm's skin is more acute in some respects than the sense of taste in man. He suspended worms over different solutions so that they could be dipped in quickly. By varying the strength of the solutions and recording the time it took worms to withdraw from them a rather accurate test was made.

The alimentary canal of the earthworm is well suited to extract the small amount of nutriment from the rather indigestible soil. The soft, finger-like prostomium above the mouth continually scrapes away particles so that they may be sucked inside and swallowed by the muscular pharynx. After passing the pharynx and esophagus, the food is held in the large thin-walled crop until it can be received for grinding in the tough gizzard. When thoroughly pulverized and mixed the mass enters the intestine where it is digested with glandular secretions and absorbed. The large amount of sandy grit in the food, though furnishing little or no nourishment, helps to grind up organic materials, just as the gravel does in a chicken's gizzard.

The cœlom of the earthworm is not continuous, but is cut off at the end of each segment by a membrane, or septum (Fig. 16). The watery fluid in the body-cavity therefore cannot pass freely from one end of the body to the other as

in Ascaris. This is of small consequence, however, for Lumbricus has a well-developed circulatory system of the closed* type, with arteries, veins, capillaries, and contractile vessels. The blood is forced forward by contractions in the walls of the large dorsal vessel, flows through the arteries to capillaries among the internal organs and in the skin, then returns to the dorsal vessel through veins. The blood acquires nourishing substances from the digestive system and is aerated in the skin capillaries. Like that of vertebrates, it carries both nourishment and gases. Respiration is carried on wholly through the skin, waste gases being eliminated from the blood and replaced by oxygen. The earthworm's blood contains hæmoglobin, and is hence an admirable carrier of carbon dioxide or oxygen.

An earthworm is well provided with excretory organs, for nearly every one of the hundred or more metameres contains a pair of nephridia. These are slender tubes which coil about in the cœlom, and are therefore well situated to absorb and eliminate liquid waste products. A nephridium begins with a closed funnel-like expansion in one metamere, passes back through a septum into the next, coils back and forth three times, and opens to the exterior through a little pore in the body wall.

Self-protection.—Lumbricus is much sought for food by robins, shrews, and other animals. It is perfectly helpless when captured, but escapes from many of its enemies by remaining underground except at night. When some animal tries to pull it from the burrow, all the setæ are protruded and cling with great tenacity. If the body breaks in two under the strain no particular harm results. To be sure, the portion remaining with the enemy is speedily devoured and digested, but that in the burrow soon grows the parts needed to make a complete body and is "as good as

* In a closed circulatory system the blood is always within the vessels and passes through a regular course; in an open system it flows in part through vessels, but also enters large irregular spaces, or sinuses.

new." There is a limit, however, to the ability of fragments to grow into complete worms. If a piece containing only a few metameres is cut from the anterior or posterior end, a double-headed or double-tailed monster, which is incapable of sustaining itself, is produced. Professor T. H. Morgan has made many curious monstrosities by grafting parts of earthworms together—individuals with the body single in front and double behind, long composite worms made by fusing parts of two or three individuals, etc.

Earthworms escape dry seasons and the cold of winter by burrowing deep in the ground and collecting together in clumps for mutual protection. The slime which is secreted from the surface of the body forms a tough coating on the inside of the burrow so that there is little danger of obstruction by the caving in of dirt. The tunnel is thus always open for a quick retreat if the necessity arises.

Race Preservation.—Earthworms are hermaphroditic but not self-fertilizing. During the breeding season two individuals frequently come together so that their anterior ends overlap, and a slime tube is secreted about the bodies of both (Fig. 83, B). The openings which discharge spermatozoa in each worm are thus brought opposite the little cavities for receiving sperm in the other individual. When the pair separate each has been supplied with sperm by the other (that is, four little pockets in the skin have been filled with spermatozoa), and each is prepared to lay fertile eggs.

Every mature earthworm has a smooth swollen region, the clitellum, near the anterior end of the body. This gives off a glandular secretion which forms cocoons for receiving eggs and protecting them during development. When a worm is about to deposit a cocoon the clitellum forms an elastic, membranous band which is slipped off over the anterior end of the body, just as a ring slips from a finger. As the band passes over the openings of the female reproductive ducts, eggs are discharged inside it; and as it goes across the pockets where the spermatozoa are stored some

of the male reproductive cells are also set free within the moving band. When it pasess off the body, the ends contract and a little hollow cocoon is formed. The eggs are fertilized inside the cocoon and undergo the usual series of developmental stages (Fig. 64). The first young worm to hatch usually devours his younger relatives, so that as a rule only one worm is produced from each cocoon. A "fertilized" earthworm does not use all its stored sperm at once, but may produce a dozen or more cocoons after each mating.

GENERAL REMARKS ON EARTHWORMS AND OTHER CHÆTOPODS

An earthworm's body is made up of a series of very similar segments and more than half of these may be lost without destroying the ultimate effectiveness of the bodily machine. If the control of the earthworm's functions was strongly localized at the anterior end, as in some bilaterally symmetrical animals, such a loss could not be sustained. In this particular, then, the worm presents a primitive condition of metamerism, which is said to be *homonomous*, because the body segments are much alike.

An earthworm's nervous system is not strongly centralized but is made up of a series of short overlapping units. It consists of a dorsal ganglion near the anterior end, two nerve trunks around the esophagus, and a ventral chain of metameric ganglia throughout the rest of the body. As a worm crawls along the impulse for contraction originates at one end and is passed slowly down the whole length. For example, if the circular muscles at the anterior end contract, the same set of muscles is progressively stimulated, and a wave of contraction passes backward. If the worm is cut in two and then stitched together with a thread so that there is a space of several inches between the cut surfaces, the worm moves about as if it had a continuous body; the pull exerted by the forward piece stimulates the one behind to move in the usual way. Such behavior shows that the

crawling movements are brought about by "chain reflexes" which pass down the body, each part setting off the one behind.

The earthworm possesses a great number of small sense organs which, though slightly more abundant toward the ends, are distributed rather uniformly in the skin throughout the body. It is able to taste or smell with equal facility at any point on the outer surface and therefore shows little or no cephalization of the chemical sense. An earthworm has no eyes, but is sensitive to light over its whole surface, and in this respect also shows a diffuse condition. In each segment of the body, sense organs are less abundant in the middle and more numerous toward the anterior and posterior ends. When the body is contracted, therefore, the majority of these organs are folded into the grooves between the segments, and cannot be stimulated. It is possible that the earthworm may rest by contracting the body to cover most of the sense organs, just as a man closes his eyes when asleep.

Though the earthworm is structurally and physiologically a chain of short units which work with more or less independence and in a rather mechanical way, it is able to carry on some activities which require the correlation of all parts of the body. Above the pharynx is a ganglion, or "brain," and there are three giant nerve fibers which run through the whole nervous system from end to end. When the entire body wiggles, the activities of the short nervous units are probably controlled and coördinated from the brain through these long fibers. There is also one type of sensation which is apparently localized at the anterior end. If an earthworm is allowed to crawl about on a moist surface of limited area, it withdraws when it comes to dry spots at the edge, but if the prostomium (or upper lip) is removed such reactions cease. The ability to discriminate between wet and dry surfaces is, however, the only sense that is known to be thus localized.

Though the earthworm and its close relatives are rather

strictly homonomous in their metamerism, there are many other chætopods which are heteronomous. Many of the marine worms have a distinct head which may bear several eyes, tentacles, and other sense organs (Fig. 84, B), thus showing cephalization. Some have the metameres differentiated into several groups, so that there are separate body regions with more or less distinctive functions.

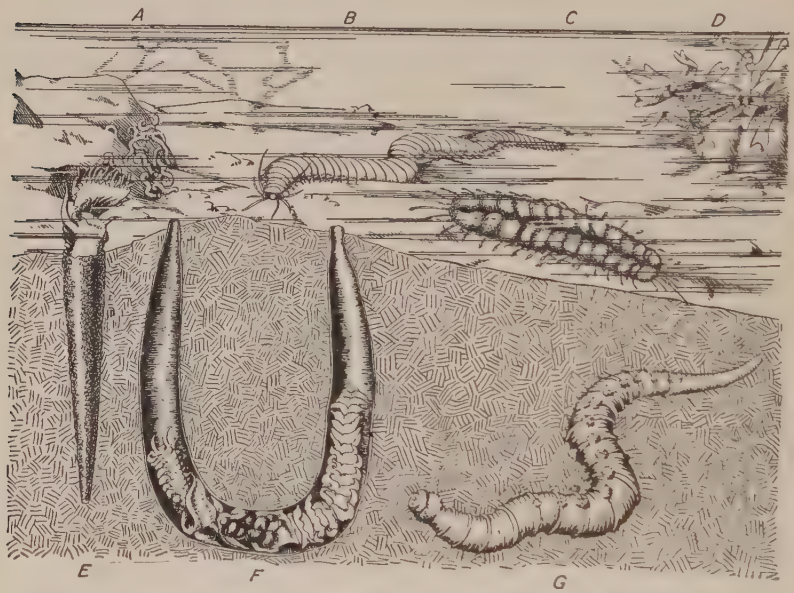


Fig. 84.—Marine annelids on sea bottom. Some burrow through the mud, others make tubes of leathery secretions, sand grains, bits of seaweed or lime, which are buried in the mud or attached to rocks, piles, and seaweeds. A, *Hydroides* in calcareous tubes on a rock; B, *Nereis*; C, *Polynœ*; D, *Spirorbis* on seaweed; E, *Cistenides* in sand tube; F, *Chætopterus* in leathery tube; G, *Arenicola*.

Chætopods are divided into two great groups. The *Oligochæta* (few bristled) are mostly confined to land and fresh water, the earthworms being common examples. The small aquatic oligochætes have rather long setæ and are often beautifully transparent. Under the microscope all their internal organs may be seen through the body wall. The *Polychæta* (many bristled) are mostly marine and show great variation in structure and habits. Many species live

in tubes which they make from secretions and bits of foreign substances, such as sand (Fig. 84, E), lime (A, D), and mucous secretions (F). Many of the tube-building species have gills on the head, and when these are brightly colored they often make the bottom of the ocean look like a flower garden. Some polychætes have the dorsal surface covered with spines or protective plates (C).

CLASS 2. HIRUDINEA

Leeches (Fig. 85), are found in fresh water, on land, and to some extent in the ocean. They are without setæ but have

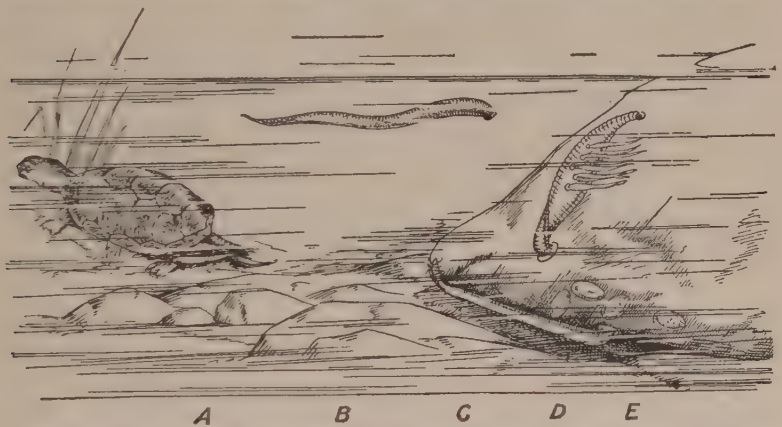


FIG. 85.—Leeches. A, attached to a turtle's leg; B, swimming; C, hiding beneath a rock and protruding proboscis to catch an insect larva; D, an adult carrying young attached to its ventral surface; *E*, egg cocoons.

a sucker at either end. The rings on the outside of the body are much more numerous (70 to 100) than the body metameres (33). On account of the thickening and distortion of the septa, the metamerism within the body is obscured; in fact, is not apparent except in the excretory and nervous systems. The cœlom is small when compared with that of chætopods.

The anterior sucker of a leech contains the mouth, but the one at the posterior end is merely an adhesive disc, and the anus opens in front of it on the dorsal side. Leeches

vary greatly in their food habits. Some live largely on insect larvæ (Fig. 85, C), others are scavengers, but the most important are blood suckers. Some of the blood suckers puncture the skin with a muscular proboscis, others bite a hole with three small teeth. A substance is secreted which inhibits the coagulation of the blood, so that there may be no interference with feeding. The alimentary canal is large and has several side pockets. When an opportunity occurs, a leech gorges itself and is then able to go for several months without food.

The breeding habits of leeches are of particular interest. In some species one individual sticks a packet of sperm on the outside of another, and the spermatozoa bore in through the skin. This unique method of fertilization is known as hypodermic impregnation. Many leeches produce cocoons like those of earthworms which are stuck on the underside of rocks (Fig. 85, E); others carry the eggs and young fastened to the ventral side of the body (D).

CHAPTER XX

PHYLUM MOLLUSCA

Molluscs are bilaterally symmetrical, unsegmented animals which usually have a ventral muscular foot and commonly possess a calcareous shell. All have a mantle of some sort. This is a covering which may have various uses, such as protecting the body, forming the shell, and swimming. Between the mantle and the body proper there is a space, the mantle cavity, which is of great importance in the activities of molluscs. There are five molluscan classes, but only three are of general importance.

Class 1. Gastropoda; snails, slugs, nudibranchs; with a large flat creeping foot, and usually having a spirally coiled shell.

Class 2. Lamellibranchiata: clams, oysters, ship worms; with an axe-shaped foot and a shell composed of two valves.

Class 3. Cephalopoda: squids, cuttle-fishes, devil-fishes, octopi; with the body elongated and the foot divided into a number of arms, which usually bear suckers; shell usually small and inclosed within the mantle, or absent.

CLASS 1. GASTROPODA

THE POND SNAIL, *Physa gyrina* Say

Self-maintenance.—Physa (Fig. 86) lives among aquatic plants where there is an abundance of food. It moves about by making muscular movements of its broad ventral foot. If a Physa is observed from beneath while crawling in a glass dish, little waves will be seen to follow each other from one end of the body to the other. These indicate bands across the body where the foot is temporarily pulled away from the glass and moved forward a little. This is a slow method of progress, but sure. As the snail moves along a slimy trail is left behind, and the slime is of consid-

erable importance in locomotion; in fact, movement is not possible without it.

Physa is able to vary its density to some extent by pulling the body forward or backward to increase or decrease the air space at the apex of the shell and can therefore rise to the surface of the water or fall to the bottom without being in contact with any solid object. This permits it to spin threads of slime in all directions between the aquatic plants (Fig. 86). The slime threads are sticky and act as traps,

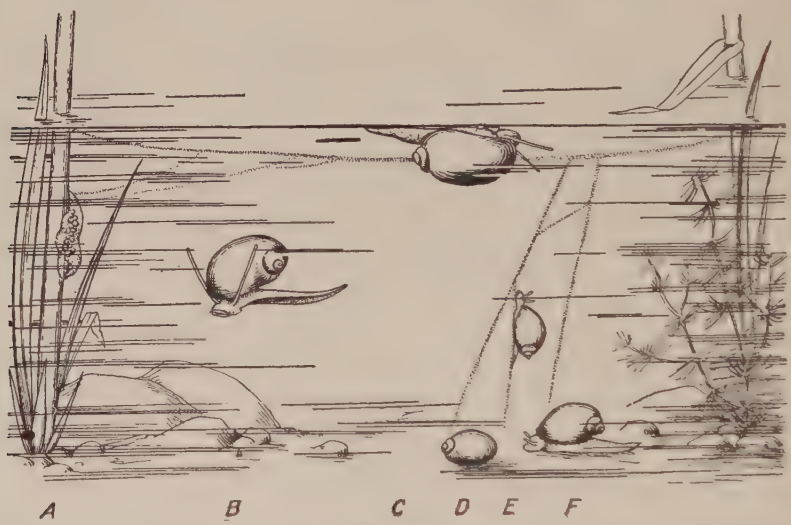


FIG. 86.—Activities of the snail, *Physa*. A, eggs in jelly attached to a plant stem; B, dropping from surface; C, taking a breath through the surface film; D, resting; E, crawling on slime thread; F, crawling on bottom.

catching minute plants and animals. After they have been in the water for a time, Physa eats them to secure the accumulated food. They are also made use of as roadways in passing from one part of a pond to another.

Physa is largely vegetarian in its food habits. Aside from the minute particles captured by the slime threads, it gnaws away parts of plants with its rasp-like tongue, and eats the scum off the surface of the water. The tongue, or radula, of a snail is a very complicated mechanism, with a

great number of little teeth arranged in regular rows and an elaborate system of muscles.

A snail's digestive system is of the tubular type. Food is mixed with the secretion from salivary glands in the mouth, passes down an esophagus into a crop, where it may rest for a time; then enters the stomach and is mixed with glandular secretions. A curved intestine leads from the stomach to the anus, which, instead of being at the posterior end, is situated in the edge of the mantle, high on the left side of the body. The peculiar position of the anus has been brought about by the twisting of the snail's body in order to become adjusted to the shell. The spiral coil of the shell makes it very economical of space, but has twisted the soft parts of the body to such a degree that some of these on the left side have become rudimentary or absent.

Physa has a closed circulatory system, with a heart, arteries, veins, and capillaries which distribute the colorless blood to all parts of the body. Blood-vessels are spread out abundantly in the walls of the mantle cavity, and it is there that respiration takes place. Physa is a pulmonate gastropod (a snail which breathes air) and the mantle cavity serves as a lung. It comes to the top of the water at intervals, protrudes its breathing tube through the surface film (C), takes a deep breath of air, and is then able to remain submerged for some time. On account of the twisting of the body Physa has only one kidney, the right. It consists of a glandular portion, which is close to the pericardial chamber, or the space around the heart, and a long tube which opens to the exterior near the anus.

Self-protection.—Physa is protected by its calcareous shell, which furnishes an ever ready retreat in time of danger, and shields it from the cold of winter. The shell also makes it possible to endure drought, and Physa sometimes lives for a time in the mud left after a pond has dried up. It is not a protection from all dangers, however, and many fish (perch, pumpkinseed, rock bass, etc.) commonly eat snails whole.

In addition to dangers which threaten from without, Physa is the subject of attacks by insidious enemies which live within its body. Chief among these are the trematodes, which pass their larval stages in snails and then pass out to mature in other animals (page 179). Against such parasites Physa probably has no means of protection.

Race Preservation.—Snails are hermaphroditic and during mating both the individuals taking part are usually fertilized. Physa lays its eggs in a little drop of jelly (Fig. 86, A). This adheres to solid objects in the water, protects the eggs, and furnishes nourishment for the young snails developing in it.

The development of fertilized snail eggs is very similar to that of other metazoans (Fig. 64), except in regard to the cleavage. In very early cleavage stages cells of different sizes are formed. Instead of lying one above the other, they become spirally twisted (=spiral cleavage). By the direction of the twisting, the form of the shell which is to be formed is indicated. Snails are of two sorts: right- and left-handed, according to whether the shell coils like a right- or a left-handed screw. Physa is left-handed, but most of the other common snails are not, and this fact may usually serve for identification. It is of particular interest that the direction of coiling of the shell is indicated in the very earliest cleavage stages.

Young Physas remain within the jelly for a time after they are fully formed; then break out and are at once able to shift for themselves. The parent takes no care of the eggs after they have been laid.

GENERAL REMARKS ON GASTROPODS

Taking the animal kingdom as a whole, the most specialized and most successful animals are those which have become able in their racial evolution to live on land. Among the few groups that have become perfectly adjusted to terrestrial life, snails have an interesting place because they

show, at the present time, all stages of transition from ocean, to fresh water, and to land. Most marine snails breathe directly from the water through feather-like gills, and have a free swimming larva (veliger). The fresh-water species do not have free swimming larvæ and, though many breathe like their marine relatives, some, like Physa, have rudimentary gills and respire air through the walls of the mantle cavity. Succinea is a common swamp snail which is amphibious. It breathes air, but may live in the water or on land, and is as often found perched on the top of a cat-tail as among the plants under water. Land snails lay their eggs in holes in the ground and in rotten logs; they all breathe air into the mantle-cavity and are without gills.

Several of the large marine snails are of considerable economic importance because they are pests to oyster and clam fishermen. They bore holes in the shells of other molluscs with their radulas and extract the soft parts. The slugs, which are snails with very rudimentary shells, and other land snails often do damage to gardens by gnawing holes in the vegetables. The large snail in Europe, *Helix pomatia*, is a source of trouble in vineyards and fields, but is also of value as a food. It is raised in "snail farms" and gathered in the fields for local consumption and export. Most of the edible snails used in the United States are sold to the restaurants in the large cities. The Department of Agriculture has recently issued a bulletin describing methods of culture and suggesting that snail farming be undertaken in this country.

CLASS 2. LAMELLIBRANCHIATA

Here belong the clams, mussels, oysters, scallops, ship worms, and other "bivalves." These animals obtain their food by siphoning large quantities of water through the mantle cavity and retaining the minute particles. Currents created by the cilia covering the body and mantle bring in small plants and animals which are swept into the

mouth. The whole alimentary canal is ciliated and the muscles accordingly take little part in moving the food through it, which is very unusual.

Most lamellibranchs move very slowly by protruding the foot (Fig. 87 A′, *f*) and pressing against the bottom, but some

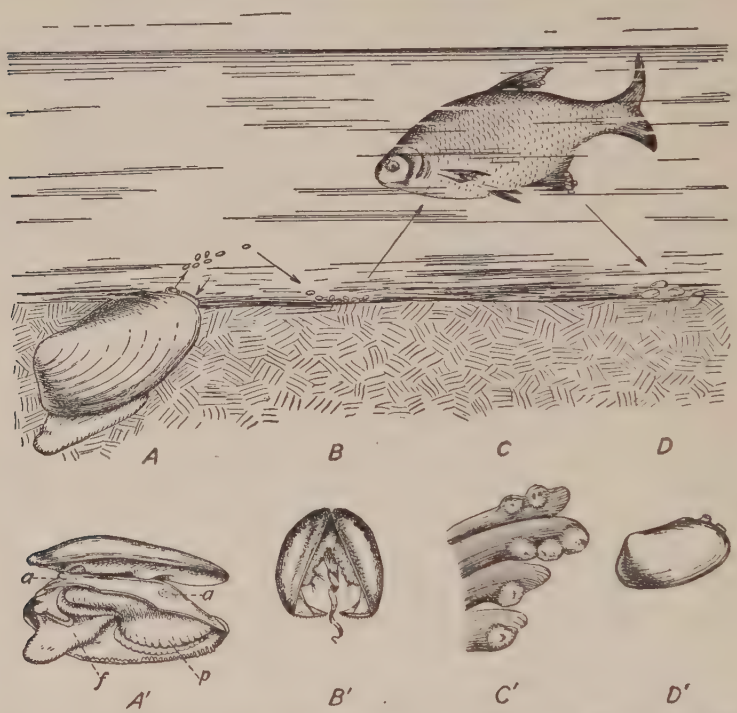


Fig. 87.—Life history of fresh water mussel. A, adult clam giving off glochidia through excurrent siphon; A′, anatomy of mature clam; *a*, adductor muscle; *f*, foot; *p*, marsupium, or swollen portion of gill, in which glochidia mature from eggs. B, B′, young glochidia on bottom; C, C′, glochidia encysted in fishes' fins; D, D′, young clam.

clams are able to leap a short distance; the scallops swim actively by squirting water from the mantle cavity, and the fresh-water *Sphæridæ* climb about on aquatic plants. A number of clams are able to burrow with great facility. The oyster moves about only while young, for it grows fast to the bottom and is then unable to change its position. On this account oysters are often smothered by mud

deposited after storms or floods. The ship worm, *Teredo navalis*, bores in piles, wharves, and even in wooden ships; hence is very destructive to timber. It is soft and worm-like, the shell being restricted to one end of the body and serving as an auger for boring.

The breeding habits of lamellibranchs are quite variable. Most of them are dicœcious and some species show sexual dimorphism, the females usually being larger than the males. Marine species usually have a free-swimming larva (veliger) which is trochophore-like (page 190), but those in fresh water generally bring forth living young. The life history of the fresh-water mussel (Fig. 87) shows great specialization and is well-adjusted to conditions in rivers, ponds, and lakes. The eggs are fertilized within the mantle cavity of the female; then pass into the gills, which serve as brood-pouches, or marsupia, and become greatly swollen. The larvæ developed within the marsupia are known as glochidia, and there are two types, hooked (Fig. 87, B′) and hookless. Both are usually set free in the water and lie on the bottom until a fish comes into contact with them. A hooked glochidium becomes attached to the fish's fins (C) and grows for a time as a parasite within a cyst. The hookless glochidia live as parasites on the gills of fishes. Both types mature within cysts, then break out, ready to take up the usual activities of young mussels (D).

Lamellibranchs are of great economic value in the United States. Along the seacoast oysters, clams, mussels, and scallops are collected for food. The national and state governments maintain laboratories for the propagation and study of these important natural resources. The ship worm, on the other hand, causes great losses and the government is trying to find better means to control or exterminate it. Pearls are formed when small foreign bodies or parasites lodge in the mantle of a clam and become covered with layers of lime. In the United States the chief source of these jewels is from the fresh-water mussels which are dredged from the bottoms of rivers and lakes. The shells

of lamellibranchs are also the source of pearl buttons, and along the Mississippi River a large number of persons (3592 in 1915) are engaged in collecting mussels for this industry. A recent publication of the Bureau of Fisheries lists forty species which are of value.

CLASS 3. CEPHALOPODA

Most cephalopods (Fig. 88) are far too active to carry a heavy exoskeleton about, and the shell is as a rule absent or

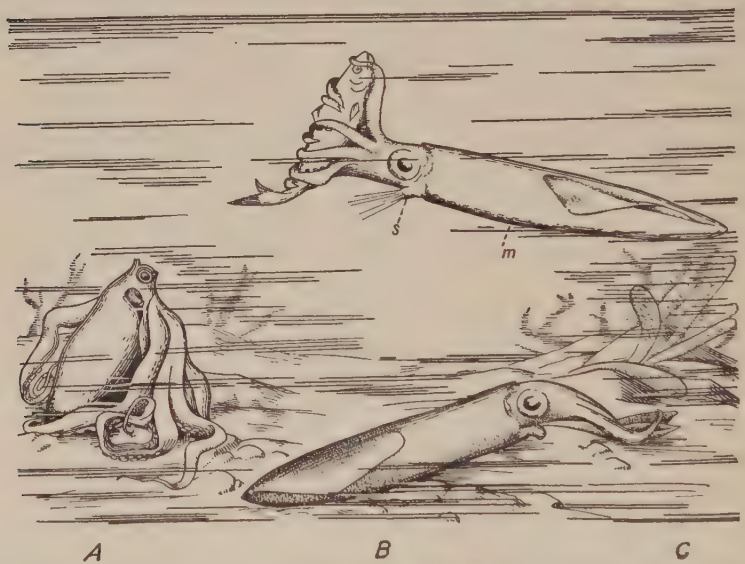


FIG. 88.—Cephalopoda. A, an octopus or devil-fish; B, squids swimming with fish and resting on bottom; *m*, mantle; *s*, siphon; C, squid eggs.

small and enclosed within the mantle. Aside from the rare nautiloids, there are two common types of cephalopods: (1) squids, are elongated, have ten arms, and swim actively; (2) devil-fishes, or octopods, have eight arms, climb more than they swim, and have short bodies. The mantle (*m*) in all cephalopods forms a muscular tube which encloses the whole body, except the head and arms. The method of swimming is peculiar. Water is drawn into the mantle

cavity and forced out of the siphon (*s*) so powerfully that the whole animal is propelled through the water backward. This movement is accelerated and guided by the lateral fins, thus making cephalopods expert swimmers.

The food of these molluscs consists of small fish and other marine animals. After being captured, the prey is held with the suckers on the arms, torn apart with the parrot-like beak, and ground up somewhat by the radula before passing down to the stomach. On account of the contractions of the mantle while swimming, all the internal organs are subjected to great pressure and food would be regurgitated through the mouth if special valves were not present. Valves are also present in the blood-vessels to prevent back-flow, and there are two accessory hearts which pump blood through the plume-like gills.

All cephalopods have large eyes on the sides of the head. These resemble those of vertebrates in their general plan, but differ markedly in details of structure and in development. The eyes enable squids and octopi to see with great acuity, and the pursuit of active animals for food is therefore easy. When a squid or an octopus is set upon by an enemy, a great cloud of ink is squirted into the water through the anus. Its movements are thus obscured, and escape is made possible.

The breeding habits of cephalopods are very peculiar. A male takes a spermatophore, or packet of sperm, on one of his arms and places it within the mantle cavity of the female. When a female lays her eggs she ruptures the spermatophore, a great cloud of spermatozoa swarm over them, and fertilization is thus insured. In some species the male breaks off the tip of his arm and leaves it in the female with the spermatophore enclosed. When this arm tip was first discovered by one of the older zoologists, it was described as a parasitic worm which was believed to live within the female. A female squid or octopus deposits her eggs on the bottom of the ocean or attaches them to a

sea-weed (C). She then leaves them to develop without further care.

Squids are commonly eaten for food in Italy and are coming to be used in other countries. They are also much sought for bait by fishermen. Though some squids attain a total length of forty feet, they are as a rule very shy, and their reputed attacks on men are probably fictitious.

GENERAL REMARKS ON MOLLUSCS

The Mollusca are remarkable among other phyla of bilaterally symmetrical animals because they are complex in structure but strictly non-metameric. Though the trochophore-like larva (page 190) indicates possible affinities with the Annelida, Echinodermata, Rotifera, etc., the structure of adult molluscs is wholly unlike that of other animals. The Mollusca therefore have no close relationship with any other phylum, and have developed along original lines.

The most striking characteristics of the phylum as a whole are the foot, the shell, the mantle, and the simple nervous system, but all these structures differ greatly in different classes. The foot is flat in gastropods, hatchet-shaped in lamellibranchs, and divided into eight, ten, or more arms in cephalopods. The shell is univalve in gastropods, bivalve in lamellibranchs, and usually rudimentary or absent in cephalopods. Squids and devil-fishes have a sac-like mantle which encloses most of the body; clams usually have the mantle divided into two great lobes, completely covering the soft body; but in snails the greater part of the body may be extended outside the mantle cavity.

Except in cephalopods the nervous system is as a rule poorly developed and its structure is rather similar in all the classes. It consists of three or four pairs of ganglia and a few connective nerves. Molluscs show in a striking way that the degree of specialization in nervous structures is associated with activity. Most of the slow, sluggish clams

are practically without special sense organs (except those for balancing the body and for testing the surrounding water), and depend largely on reflexes in their daily activities, but the scallops (Pecten) which swim actively have a double row of eyes around the edges of the mantle. The snails are somewhat more active than clams, and have simple eyes, organs of taste, and other sensory structures, but are at best rather slow. The most active molluscs are the cephalopods, and they show the most elaborate sensory organs: well-developed eyes, balancing organs, taste organs, etc.

The mental powers of all molluscs are very limited. As would be expected from their superior sensory equipment, the cephalopods excel other members of the group. They are able to see and pursue their prey, elude their enemies, and carry on other activities which are impossible for the sluggish clams and snails. One investigator taught a squid to take food from a hole in a glass tube, and the food was extracted more quickly after some experience had been gained.

CHAPTER XXI

PHYLUM CHORDATA

The phylum Chordata includes all the animals commonly known as vertebrates and a number of others that are somewhat less familiar. All chordates have a thick rod running through the body which is known variously as the chorda dorsalis, chorda, or notochord. This is much like a straight Bologna sausage in form and consistency, having a membrane over the outside and a filling of pulp within.

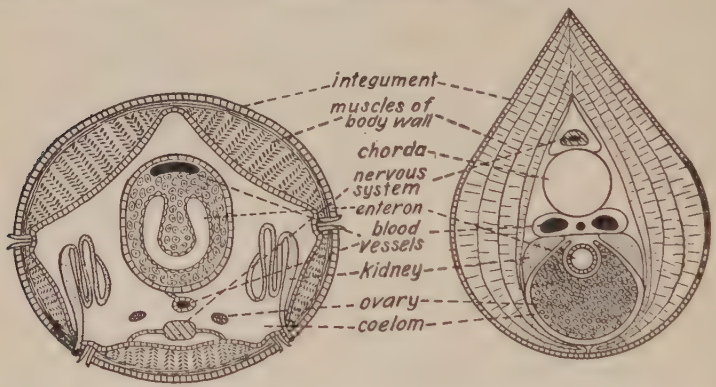


FIG. 89.—Cross sections of an earthworm and a lamprey-eel compared. Note the difference in the relative position of the central nervous system.

The chorda is strictly a skeletal structure, and has nothing to do with the spinal cord, which is a part of the nervous system.

Besides the chorda, the chordates have two other distinctive features: (1) the gill slits and the gill arches; and (2) a tubular nervous system situated dorsal to the alimentary canal (Fig. 89). The gill slits are paired openings from the pharynx to the outside of the body. In most aquatic chordates they serve as exits for the water drawn

through the mouth and used for respiration, but are present in terrestrial forms only during development. Between the slits run the aortic arches carrying blood, and these great arteries are often supported by cartilaginous or bony structures. The nervous system of chordates is formed during development by the turning in of the ectoderm on the dorsal surface (Fig. 92). At first there is simply a longitudinal depression (A), and the deeper part of this is later pinched off (B, C) to form a longitudinal tube inside the body wall (C). This tube usually becomes thickened and expanded somewhat at the anterior end to form a brain, and nerves grow out from it to all parts of the body, but even in an adult man it is still tubular in its fundamental structure.

In some of the most primitive living chordates, such as the lamprey eels and the lancelets, the chorda is functional and constitutes practically the sole skeletal structure within the body, but in the great majority of the vertebrates it is replaced to a greater or lesser extent by a series of vertebræ which together make up the spinal column, or "backbone." There is also a transition in the aortic arches in passing from primitive to more specialized chordates. The aquatic representatives have functional gill slits and well-developed aortic and skeletal arches. The frogs and toads begin active life with a fish-like form and functional gills, but later lose the gills and have the blood diverted to the lungs and skin for aeration. Reptiles, birds, and mammals never breathe through gills, but nevertheless have gill slits and gill arches during early developmental stages. The primitive arterial arches degenerate in the adults or are diverted to supply new parts with blood (Fig. 105). The skeletal parts of the arches which serve to support gills in primitive chordates are for the most part transformed into jaws, throat cartilages, and the bones of the face in more specialized types.

Thus, though the same fundamental plan of structure is present in all chordates, parts may be so modified as to

completely change their form, and have often during evolution come to serve entirely different functions from those for which they were originally used. Such changes have usually gone with modifications in modes of life. Though all the primitive chordates are largely aquatic, the specialized forms are nearly all terrestrial and hence fitted to breathe air. One of the most interesting features of the past evolution of the vertebrates has been their migration from water to land.

The phylum Chordata is divided into four subphyla.

Subphylum 1. **Enteropneusta.**—This group includes certain worm-like animals. *Dolichoglossus* lives buried in the mud along the seashore (Fig. 90, *f*). Its chorda is small and contained within a swollen proboscis which projects above the mouth. The body is divided into three regions —proboscis, collar, and trunk. A large number of paired gill slits connect the pharynx with the exterior. *Dolichoglossus* extracts its food from mud which is forced into the mouth at the front of the collar, passes through the straight enteron, and leaves the body through the anus at the posterior end.

The larvæ of some of the Enteropneusta are tornariæ, which are much like the larvæ of certain echinoderms, and resemble a trochophore (page 190) in general structure. This has led some zoologists to believe that chordates arose from a remote ancestor which resembled a trochophore, and that there is relationship between echinoderms, annelids, molluscs, and other animals originating from a trochophore-like larva.

Subphylum 2. **Tunicata.**—The sea-squirts (Fig. 90, *g*, *h*) are degenerate animals which grow attached to piles and other objects in the ocean. They are covered by tough "tunics," through which there are two openings for the entrance and exit of water. When taken from the ocean two little streams of water are ejected from the body; hence the common name, "sea-squirt." In feeding, water is strained through a porous pharynx, which catches food

particles and passes them on to the stomach and intestine. The anus opens near the exhalent aperture inside the tunic. Many species of sea-squirts are colonial and form masses known to fishermen as "sea pork" (*b*, *h*).

Some tunicates are not attached but swim at the surface of the ocean. The salpas, for example (Fig. 90, *c*, *d*) are

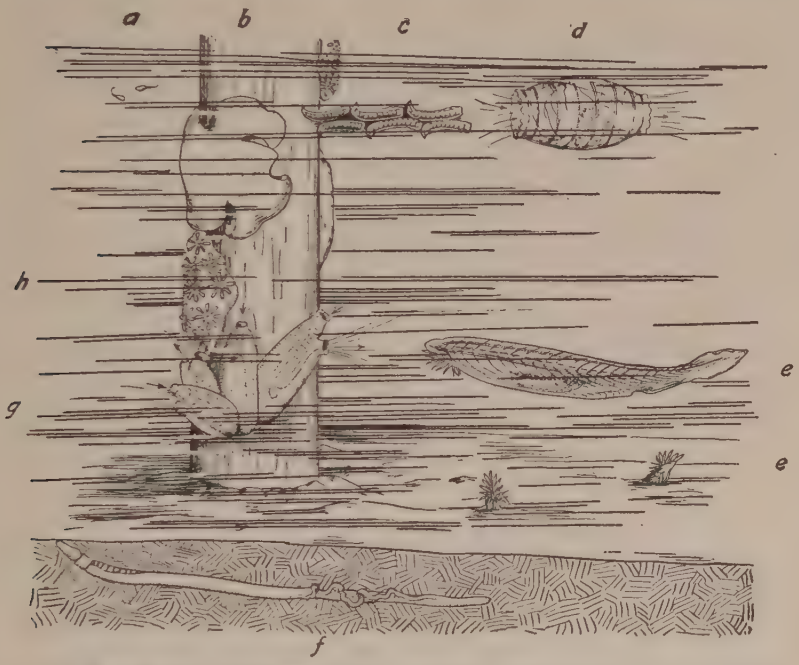


FIG. 90.—Simple Chordates. The sub-phyla represented are as follows: *a–d*, *g*, *h*, Tunicata; *e*, Cephalochorda; *f*, Enteropneusta. The separate figures are: *a*, tunicate tadpoles; *b*, *Leptoclinum*, or "sea pork," a colonial tunicate; *c*, a chain *Salpa*; *d*, *Salpa*, a swimming tunicate; *e*, *amphioxus*; *f*, *Dolichoglossus*; *g*, *Molgula*, a typical "sea squirt;" *h*, *Amarœcium*, a colonial tunicate.

beautifully transparent, barrel-shaped animals which swim by drawing water into the front of the tunic and forcing it out behind. They occur singly or in chain-like colonies. The Larvacea are another group of free-swimming tunicates which resemble minute tadpoles in their general form.

Most adult tunicates have the chorda greatly reduced or absent, but all of them develop from little tadpoles in

which it is well-developed and functional. The Larvacea (*a*) therefore represent the most primitive types. Most of the common sea-squirts have, like barnacles (Fig. 32), undergone retrogressive metamorphosis, and as adults are adapted to a sessile existence.

Subphylum 3. **Cephalochorda.**—The lancelets (Fig. 90, *e*) are small fish-like animals which bury themselves tail first in sandy ocean beaches below low-tide mark. Amphioxus is a well-known representative which has been much discussed by evolutionists as a possible ancestor of vertebrates. It has a well-developed chorda and numerous paired gill slits opening from the pharynx to the exterior. The body wall is divided into a large number of muscle segments, or myomeres. Along the whole dorsal margin there is a narrow fin which is continuous posteriorly with a broader caudal fin. On the ventral side of the body, a short medial fold (ventral fin) reaches forward from the caudal fin, and in front of this two lateral (metapleural) folds extend to the region of the mouth. The median fins and the lateral folds are continuous, but have the same arrangement as the separate fins of true fishes. The metapleural folds have, therefore, been considered to be the forerunners of the paired limbs of the vertebrates. The cephalochordates excel Enteropneusta and Tunicata in their greater cephalization and show closer affinities with the vertebrates.

Subphylum 4. **Vertebrata.**—This group includes the eel-like cyclostomes, sharks and skates, fishes, salamanders, frogs, reptiles, birds, and mammals. Most vertebrates have two characteristics which usually serve to separate them readily from other chordates: (1) vertebræ replace the chorda, which is usually present as such only during embryonic development; (2) two pairs of lateral appendages, or limbs, are present. Though vertebrates as adults are rather diverse in structure and habits, they are all built according to the same fundamental plan and pass through similar stages in development. There is, therefore, no doubt that vertebrates are genetically related and, because their evolu-

tion has been more recent than that of any other group of animals, more facts are available concerning the lines specialization has followed.

In the most primitive vertebrates the chorda is functional throughout life and the vertebræ appear only as little cartilages between the myomeres, or muscle segments. But as the complexity of the skeleton progresses in the vertebrate series, there is a transition from chorda to cartilage, and again to bone. Some vertebrates are as adults only a little beyond the chorda stage, others, like the sharks, have developed a cartilaginous skeleton, but go no further. The majority of vertebrates, however, pass through three stages in their development: (1) having a chorda, replaced by (2) cartilaginous vertebræ, which in turn give place to (3) bone. Paired limbs likewise show a rather definite sequence in their specialization. They are absent in the most primitive vertebrates and appear first as flaps supported by cartilaginous rays. Fins with bony rays are the next step, and these are later replaced by pentadactyl (five-toed) limbs. The pentadactyl limb represents a great advance in racial development when compared with a fin, but it has now been so greatly modified in many groups as to be scarcely recognizable. A bird's wing or a horse's foot show little indication of the ancestral five-toed condition. Most snakes and the blind worms have lost the paired appendages completely.

The vertebrate circulatory system also affords a good illustration of progressive specialization and development. The most primitive vertebrates have a tubular heart (Fig. 105), bent somewhat to be sure, but still nothing but a tube, which pumps blood through six aortic arches to the gills. Very soon the number of arches is reduced to four, then to three. In birds and mammals the arches appear as such only in early development, and in the adult condition all but a single arch on one side of the body have been lost or diverted to other uses. In fishes the heart presents a simple tubular condition; in amphibians and in most rep-

tiles it is three-chambered and pumps "half-pure" blood. Birds and mammals show a four-chambered condition; the blood on one side has been aerated and that on the other is charged with waste products.

There are three kinds of kidneys present in vertebrate animals. These are believed to represent parts of a continuous series of nephridia, somewhat like those of annelids, but in no vertebrate is more than one of the three functional at a time. The most primitive vertebrates (Cyclostomes) have only one kidney, the pronephros, or head-kidney. Fishes and amphibians have a pronephros during early development, but it soon degenerates and is replaced by another kidney, the mesonephros. Reptiles, birds, and mammals have first a pronephros, then a mesonephros, but their functional kidney during adult life is the metanephros, which develops after the other two have degenerated.

Other lines of vertebrate specialization might be described, but enough has been said to show that it is possible to speak in more positive terms concerning this group of animals than of any of those which have been discussed in the preceding pages. Perhaps the most interesting thing to keep in mind as we pass from primitive to specialized vertebrates, is that in general evolution has been from aquatic modes of existence to life on land. Structures and functions have been accordingly modified. The fin, for example, was good enough as an organ of locomotion in the water, but cannot compare with a jointed leg ending in toes for progress on land.

There are seven classes of vertebrates which may be briefly outlined as follows:

Class 1. Cyclostomata. Eel-like vertebrates with a chorda and median fins, but without paired fins or true jaws. Lampreys and hagfishes.

Class 2. Elasmobranchii. Fish-like vertebrates with cartilaginous skeletons, jaws, placoid scales, and a persistent chorda. Sharks, skates, rays.

Class 3. Pisces. Fish-like vertebrates with cartilaginous or bony skeletons, true jaws, scales, and fins supported by rays. True fishes.

Class 4. Amphibia. Slimy-skinned vertebrates without exoskeletons; with pentadactyl limbs; no claws on toes; heart three-chambered. The young are aquatic and breathe by means of gills; the adults are usually more or less terrestrial and breathe through lungs. Frogs, toads, salamanders.

Class 5. Reptilia. Scaly-skinned vertebrates, which breathe by means of lungs and have a three- or four-chambered heart; claws on the toes. Lizards, snakes, turtles, crocodiles, etc.

Class 6. Aves. Feathered, scaly-skinned vertebrates with four-chambered heart and warm blood, but no teeth. Birds.

Class 7. Mammalia. Warm-blooded vertebrates with hair and mammary, or milk, glands. Whales, seals, bats, dogs, horses, monkeys, etc.

CLASS 1. CYCLOSTOMATA

The cyclostomes lack true jaws and are without paired lateral appendages. The nasal pit is single instead of double as in other vertebrates, and there are from seven to fourteen pairs of gill slits. Two kinds of cyclostomes are living at the present time—hagfishes and lampreys.

The hagfishes are found only on muddy bottoms in the ocean. They bore their way into fishes in order to eat out the soft parts, and are a source of great annoyance to fishermen because they commonly attack shad, cod, and other fish caught in nets or on hooks. They have a single tooth which they use for boring into their victims.

Lampreys live both in the ocean and in fresh water. They have a cartilaginous funnel around the mouth which is used as a sucking disc for feeding or attachment. There are numerous teeth inside the mouth and on the tongue. *Petromyzon marinus* (Fig. 89, *B;* 91, *A*) is a common species about the mouths of rivers along the Atlantic coast of the United States. It lives on blood which is obtained by attaching the oral disc to fishes and rasping a hole with the tongue. The larva of this species differs markedly from the adult, and shows several characteristics which resemble those of Amphioxus (Fig. 90, *e*). Another cyclo-

stome, the brook lamprey of North America, *Lampetra wilderi*, has interesting breeding habits. Stones are carried in the mouth and a space is thus cleared in which mating take splace. This species does not eat as an adult, and is therefore not harmful to fishes.

FIG. 91.—Cyclostomes and elasmobranchs. A, lamprey-eels, resting and attacking a shark; B, shark; C, sting-ray.

CLASS 2. ELASMOBRANCHII

Elasmobranchs (Fig. 91, *B*, *C*) resemble true fishes in general form and in having two pairs of lateral fins, but differ from them in possessing a notochord when adult, placoid scales (Fig. 93), a spiral valve in the intestine, clasping organs in the male, and in lacking an air-bladder and a gill-cover, or operculum. They are therefore placed in a separate class.

There are two common types of elasmobranchs, sharks and rays. The sharks and dogfishes are cylindrical or

compressed and swim actively about seeking for food. They are voracious feeders on fish and other animals; therefore, are readily caught on a hook. Though one species attains a length of over thirty feet and sometimes attacks man, most sharks are harmless, except for their ravages among fishes and other small animals. They are of some

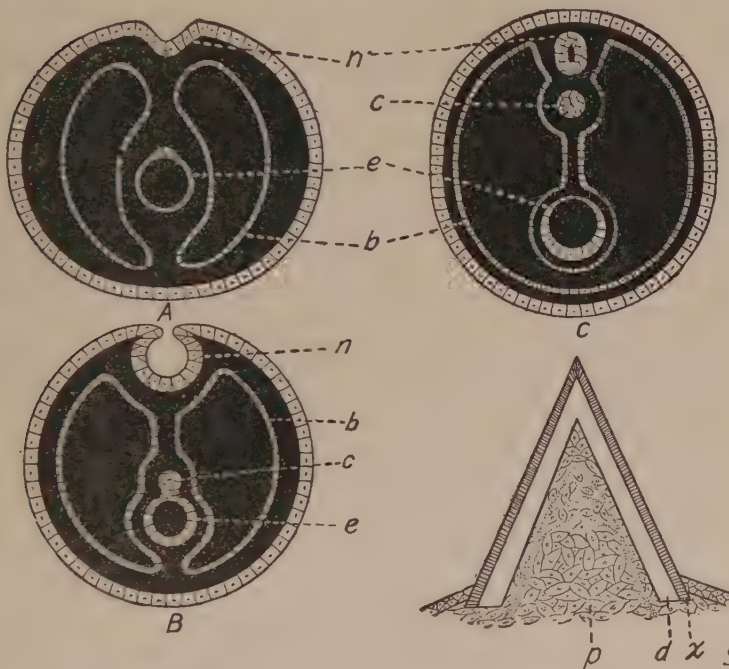


FIG. 92. FIG. 93.

FIG. 92.—Three cross sections (A, B, C) of an embryonic vertebrate to show formation of nervous system, chorda, and cœlom. *b*, membrane surrounding cœlom; *c*, chorda; *e*, enteron; *n*, nerve tube.

FIG. 93.—Section through a placoid scale of an elasmobranch. *d*, dentine; *p*, "pulp;" *x*, enamel; *y*, integument.

value as fertilizer and for the oil which is extracted from their livers. The flesh is also canned to some extent and sold as a cheap substitute for the true fishes. Sharks cause great losses by destroying lobsters and valuable food fishes.

The skates and rays have broad flat bodies and commonly lurk on the bottom of the ocean awaiting small animals

which they capture and devour. The sting ray (Fig. 91, *C*) often inflicts painful wounds on the bodies of bathers and fishermen. It has a barbed poison spine at the base of its tail which is driven with great force into any animal that molests it. A tropical ray, the torpedo, has electrical organs in its body which are under the control of the nervous system. These are capable of giving powerful shocks and serve as effective weapons of defense or offense.

The placoid scales (Fig. 93) of elasmobranchs are of particular interest because their structure closely resembles that of the teeth in the mouths of true fishes, amphibians, reptiles, and mammals. Each is covered with a layer of enamel, which surrounds a bony dentine layer, and the interior is filled with "pulp" containing blood vessels, nerves, and connective tissue. It is believed that the teeth of vertebrates have been derived from placoid scales such as the sharks and rays possess. In elasmobranchs these organs occur in the skin over the whole body and in the mouth. Those in the mouth are on a portion of the ectoderm which has been turned inside; they are particularly large and arranged in regular rows. In other vertebrates the teeth are restricted to the mouth, or in other words, placoid scales are lacking from the skin.

CHAPTER XXII

SUBPHYLUM VERTEBRATA, CLASS 3, PISCES

In true fishes the chorda is usually replaced by bony vertebræ, the gills are protected by an operculum, or "gill-cover," and the body is covered with scales which are never of the placoid type, as in sharks, but consist of little bony plates which overlap like shingles. In general form and position the fins are much like those of sharks, but are often supported by bony rays. There are two subclasses of fishes:

Subclass 1. Teleostomi. Fishes with a skeleton composed largely of bone; with gills, but usually without lungs.

Subclass 2. Dipnoi. Fishes with a skeleton made up of cartilage and bone, and with a single or paired lung.

As an example of the subclass Teleostomi, the yellow perch, which is one of the commonest and most widely distributed fishes in North America, will be considered.

THE YELLOW PERCH, *Perca flavescens* Mitchill.

Self-maintenance.—The perch (Fig. 94) is versatile in every way, and this is particularly true of its food habits. It may feed on microscopic animals in the water such as Daphnia or Cyclops (Fig. 31), or eat snails, insect larvæ, aquatic insects, minnows, fish eggs, and even plants. The minute animals are secured by straining the water which is continually entering the mouth for respiratory purposes and passing out behind the operculum. This straining is accomplished by a series of minute finger-like projections, the gill-rakers, attached along the inner margins of the gill-arches and spread across the spaces where water leaves

the body. Small particles of food are caught and held until they can be swallowed. A perch may swim about in a swarm of microscopic animals (Fig. 94, *B*) and strain out enough of them to completely fill its alimentary canal. For capturing larger prey, such as minnows and insects, the perch's mouth is provided with sharp, backwardly

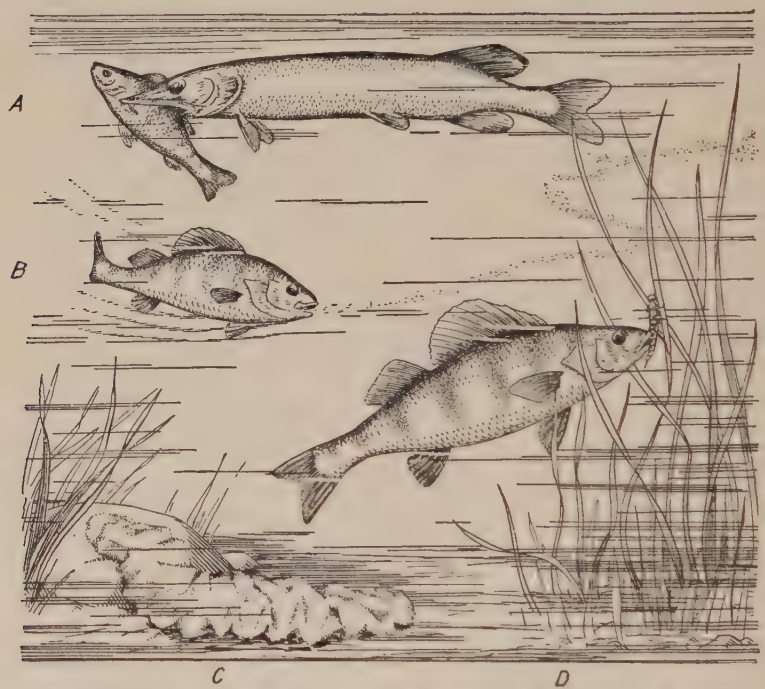


FIG. 94.—The perch, *Perca flavescens*. A, caught by a pickerel; B, catching minute animals for food; C, egg string; D, capturing a dragon-fly nymph.

directed teeth, which, though not used for chewing, serve to prevent the escape of wriggling animals.

A perch is a very good swimmer and is even able to leap out of the water to capture small animals. Its shape is such that it can be reasonably successful in any habitat in fresh water. In this respect it differs from fishes which are restricted to certain situations. The basses and sunfishes, for example, are fitted structurally to feed among aquatic

vegetation; suckers have their mouths turned downward for feeding from the bottom. Perch are equally at home in the depths of lakes or in the dense growth of plants alongshore; also thrive in ponds and streams. They can feed from the surface, strain microörganisms from the open water, snatch snails and the larvæ of insects from their retreats among plants or stones, and grub about in the soft bottom mud for minute worms and insect larvæ.

In its sensory equipment for finding food a perch presents a rather generalized condition when compared with many other fresh-water fishes. A bullhead, for example, pays little attention to moving objects unless they touch it, but seeks food by swimming so that the body swings from side to side. The "whiskers," or barbels, which bear taste organs, thus encounter a considerable part of the area being explored. If a barbel touches something that is suitable for food, the fish at once turns and snaps up the morsel. A trout, on the contrary, depends little on its senses of taste and smell in seeking food, but is quick to investigate any small moving object. It chases bubbles, pursues floating twigs, and examines everything that moves in its immediate vicinity, thus capturing many small insects and other organisms. The bullhead in hunting depends primarily on its senses of taste and smell, the trout uses its sense of sight more than any other. The perch, however, has enough versatility to feed in various ways and therefore has greater opportunities for securing food. Its acute eyes enable it to feed on the small moving things sought by the trout; its sense of taste, though not distributed so widely in the skin as that of the bullhead, is still good enough to be of value in locating and judging the value of food. The presence of food substances may also be known through dilute solutions given off in the water which are perceived by the sense of smell. If anything moves that promises food it is investigated and perhaps even taken into the mouth, to be rejected again if not suitable. If there is a flavor of snail, or worm, or insect in the water, it is followed to its source. Small

wonder, then, that perch usually exceed other fishes in numbers. They are far too versatile to be kept down by scarcity, or other variations in the food supply.

When food enters a perch's mouth, it is taken charge of by the digestive system, and passes down the esophagus to be digested and absorbed in the stomach and intestine. There are three little pockets, or cæca, which enter the intestine just behind the stomach and help to increase the surface. The liver, pancreas, and intestinal glands pour their secretions into the intestine to be mixed with the food. Undigested parts collect in the rectum and are eliminated through the anus. Absorbed food enters the circulatory system and in the blood is distributed to all parts of the body. The blood is pumped by the heart to the gills, where aeration takes place. It then passes through the four aortic arches (Fig. 105) before passing to the head and to the great dorsal aorta which distributes it to all parts of the body. All vessels leading away from the heart (arteries) end in minute capillaries, and these in turn open into veins which carry the blood back to the heart, to be pumped round the circuit again. In short, the perch has a "closed" blood system which carries food, waste products, and oxygen.

The important organs of respiration in a perch are the gills and the air-bladder. There are four pairs of gills, each bearing a double row of soft finger-like branchial filaments, through the walls of which aeration takes place. As water passes over the filaments, the blood in their capillaries gives up its waste products and acquires oxygen. The air-bladder serves as a storage reservoir for oxygen and enables a perch to invade stagnated regions without danger of suffocation. It contains a high percentage of oxygen and this reserve is used when the surrounding water does not contain a sufficient supply.

Waste products accumulating in the blood are carried to the kidneys for elimination from the body. A kidney consists of a vast collection of uriniferous tubules, or nephridia, which are individually somewhat like those described in the

earthworm (page 206), but are not metamerically arranged. The ureter is a duct which carries urine from the kidney outside the body.

Self-protection.—The chief enemies of perch are large predaceous fishes (the pickerel, bass, dogfish) and man. Piscivorous enemies usually lurk in the shore vegetation, and capture their prey by fierce and sudden rushes. From these perch are protected to some extent by various habits and adaptations, but from man, with his nets, hooks, spears, and traps, there is no escape.

A perch is well protected from slight injuries by its covering of scales. If caught by a pickerel, or some other enemy (Fig. 94, A), it spreads its fins so as to inflict painful pricks when the bony rays are touched. There are also sharp saws along the edges of the opercula which may cause severe cuts. These are made more effective by spreading the opercula to their greatest extent when danger threatens. The slimy skin and the backwardly directed scales make a perch difficult to hold, for with every wriggle the body tends to slip forward a little.

Fishes have a row of peculiar sense organs extending along either side of the body. These are known as the lateral lines, and are believed to serve for the perception of very slow vibratory movements in the water, such as would result from the splashing of falling bodies. The lateral line organs would therefore be of value in giving notice of disturbances in the water.

The body of a perch is "countershaded" by being paler below, so that when light strikes it from above, the dark back with its brighter illumination is equal to the lighter belly in the shadow. The dark vertical bands blend readily with the lights and shadows in the shore vegetation, or merge with the ripples on the surface of the water when seen from below. A perch, like other fishes, may change its color somewhat to suit the background on which it customarily rests. Such changes are brought about by the expansion and contraction of certain pigmented cells in the

skin. If kept on a black background for a month, a perch will become very dark, and if allowed to remain on a white bottom, will assume a very pale color.

Perch have considerable power of regenerating parts of the body after loss through accident or injury. A fin may be entirely lost, and will grow again. Many fish die, however, after comparatively slight injuries because fish moulds (*Saprolegnia*), bacteria, and protozoans gain entrance to the body through the wounds. Perch are very commonly infested by parasites. Nearly every individual examined will be found to have the white "bladders" of larval tapeworms in the liver or among the visceral organs. These cysts if taken into a bass or pickerel will grow into mature tapeworms. The perch's muscles, bile ducts, cæca, and intestine are also often infested with trematodes.

Perch adjust themselves readily to conditions in the temperate regions of the earth. In winter most of them retreat into the depths of lakes and rivers, where the temperature is low but conditions are uniform and small aquatic animals furnish a plentiful food supply. In migrating from one level to another modifications of the internal pressure in the body are necessary, and such adjustments are brought about largely by slow variations of the gas in the air bladder. Perch remain active throughout the year and may be caught on a hook and line at any season.

Race Preservation.—Perch, and all other teleosts, are of separate sexes. Both the males and females have large gonads (testes or ovaries) and are nearly mature before cold weather begins. During the winter both sexes become fully ripe and are ready to begin spawning in April and May. After the ice goes out the males move into shallow water and are soon followed by the females. When a female comes inshore, she is attended by one or more males. As she deposits her "egg string" (Fig. 94, C), which is a crinkled tube of jelly containing 2000 or 3000 eggs, the male squirts sperm over it and fertilization is thus accomplished.

The egg strings often hang on sticks or stones in shallow water.

The development of a perch egg after fertilization follows the usual course for metazoans (Fig. 64), but appears to be different because the embryo forms on one end of the egg. This restriction of cell-division and embryo-formation to the germinal disc is due to the large amount of yolk which fills the rest of the egg and which, though contained in the cytoplasm, is too inert to permit cell-division. The "fertilized" egg (Fig. 95, B) is a zygote formed by the fusion of an ovum (A) and a sperm cell. The nucleus of the egg cell

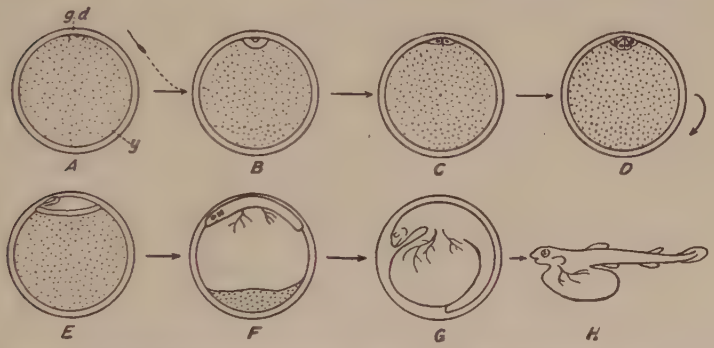


FIG. 95.—Embryonic development of fish. A, unfertilized egg; *gd*, germinal disc; *y*, yolk; B, zygote formed by union of ovum and spermatozoon; C, D, cleavage; E, young embryo showing neural groove at left; F, showing yolk nearly nearly overgrown by the vascular membrane (blastoderm) growing out from embryo; G, embryo with "yolk sac;" H, young fish, just hatched, with yolk sac not yet absorbed.

lies at one end in an area of protoplasm called the germinal disc (*gd*). The rest of the egg cell is filled with yolk material (*y*). The sperm cell enters the germinal disc, and when cleavage follows fertilization, it is confined to that area. As the embryo grows the yolk is used to nourish it (E, F, G). When the little perch is ready to hatch (G), the yolk containing part of the egg is completely invested by a vascular membrane and forms an appendage, known as the yolk sac, on the belly of the young fish. After leaving the egg envelopes, the young perch (H) takes no food until the egg sac is completely absorbed.

Perch take no care of their eggs, and may even devour them or their young. Other species of fishes often follow perch during the spawning season to feed upon the egg strings. The young are very sluggish until the yolk sac has been absorbed, then quickly learn to shift for themselves.

GENERAL REMARKS ON FISHES

The thirteen thousand species of fishes now in existence show a wide range of variation in structure and habits.

The morays and eels have long snake-like bodies; the puffers and globefishes are more or less spherical in form; the goose-fishes have very large heads, the sunfishes have large bodies and very small heads; most fishes are well covered with scales, but the catfishes have none. The fins vary greatly in size, structure and position. There is endless variation, yet all fishes are recognizable as such, for they breathe through gills and are without fingers or toes on their paired limbs.

The feeding habits of fishes are often very interesting and peculiar. The herring eats diatoms and other microscopic organisms which it strains from the ocean. One scientist has said that he could predict the herring catch by the number of sunshiny days—so directly is the growth of diatoms dependent upon light from the sun, and so important are these minute plants as food for the herring. The black swallower takes whole fish into its stomach which greatly exceed its own size. Various fishes feed exclusively on plants, or fish, or other particular foods. Some are thus greatly specialized, others will eat practically anything they encounter.

The only method of locomotion in most fishes is swimming by using the fins, but there are many exceptions. The beach skippers along the shores of some tropical seas seldom enter the water but hop about by using the pectoral fins and tail. The climbing-perch is not only able to come on land, but is said to climb trees and catch insects. Flying fishes

leave the water and sail for several hundred yards before alighting. The great majority of fishes are strictly gill breathers, but there are also some exceptions in this instance. The dipnoans are able to breathe either through gills, or respire air directly by means of lungs. Some other fishes gulp in air and breathe through the lining of the throat or intestine.

Breeding habits of fishes are highly variable and often show extreme adaptation. A cod may lay over nine million eggs, which float at the surface of the ocean and receive no care. The male gaff-topsa'l-catfish carries the eggs laid by

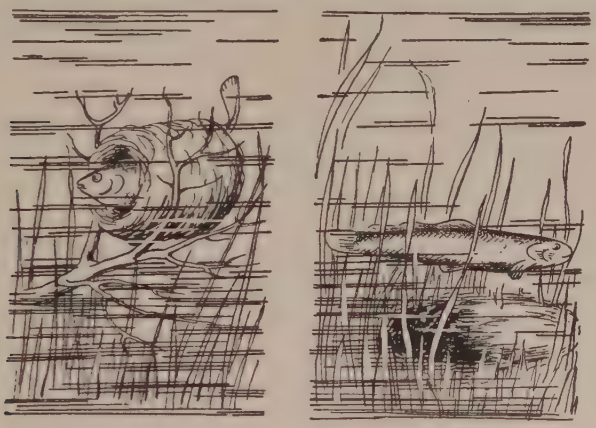


FIG. 96.—Fish nests. A, stickleback; B, dogfish.

the female in his mouth until after they hatch, and takes no food for ninety days. The male pipefish obtains eggs from a female and carries them in a pouch in his belly until after they hatch. In some species of sticklebacks the male constructs a nest (Fig. 96, A). In this he induces a female to lay eggs, and watches them with great care. Many basses and sunfishes make "nests" by clearing a shallow basin on the bottom in which eggs are deposited.

Some fishes carry on extensive seasonal migrations. The salmon, shad, sturgeon, alewife, and striped bass spend most of their lives in the ocean, but enter rivers to breed. The

king salmon on the Pacific Coast of America spawns in November, at the age of four years and when of an average weight of twenty-two pounds. It spends the whole of the preceding summer in ascending the rivers, taking no food during that time, but living on its stores of fat. The salmon that run up the Columbia River travel a thousand miles, and those in the Yukon journey twice as far. Eggs are deposited on the gravelly bottoms of mountain streams and the fish which have made the long journey die soon after. The young salmon spends more than a year in fresh water before passing down to the ocean to mature. The true eels reverse the condition found in the salmon, passing their adult life in fresh or brackish water and returning to the ocean to breed.

The behavior of fishes shows great diversity in instincts and in the use of particular sense organs. Many species depend largely on their senses of taste or smell for procuring food, others use their eyes exclusively and are quick to take any small moving object into their mouths. Carp, mud minnows, trout and other fishes have been taught to come to a certain spot to be fed, and will respond to signals, such as the ringing of bells or the display of objects of certain colors. Instincts and specialized adaptations are many, modification of behavior is often easy, but there is little or no power of reason.

Early zoologists assumed that, because fishes live in water where all chemical substances that could be smelled or tasted would be dissolved, there could be no sharp distinction between taste and smell, and some went so far as to affirm that fishes could not smell at all. Professor Parker has demonstrated, however, that fishes smell very dilute solutions in the nasal pits, and taste stronger concentrations with the lips, barbels, or other parts of the body. They therefore show the same differentiation in the chemical senses as that in terrestrial vertebrates, smell being used for perceiving greatly diluted substances and taste for stronger solutions.

The evolution of fishes has taken place during the ages still represented by the fossil records and is therefore better known than that of any phylum of invertebrates. Though the exact ancestors of modern fishes are unknown, the general course of events is pretty well recorded in the rocks. Many of the ancient groups of fishes are now completely extinct, and a number had peculiar characteristics which died out with them. Some had the body covered with heavy armor, and were provided with a rather flexible neck joint, so that the head could nod. Many lacked teeth and had no paired fins. Among fish-like animals still in existence, the cyclostomes and sharks were the first to appear in the past (the most primitive types came first), and were followed somewhat later by the bony-fishes.

Fisheries are of great economic importance in all parts of the world. The principal species serving for food are: the cod, mackerel, and salmon. In the year 1914 the total catch of fish brought to Boston and Gloucester amounted to 162,589,220 pounds and had a value of $4,395,030. The total value of the fishes captured in the United States and on their shores is enormous. The Bureau of Fisheries is constantly at work trying to increase the productiveness of fishing and improve the quality of its output. Fifty stations are maintained for propagation and study. During 1914, 4,288,757,800 eggs and young fishes were planted in suitable waters.

CHAPTER XXIII

SUBPHYLUM VERTEBRATA, CLASS AMPHIBIA

Amphibians have soft moist skins, generally without any sort of exoskeletal structures. This distinguishes them sharply from the reptiles, which have dry scaly skins. On the other hand, amphibians cannot be confused with fishes because, instead of fins, they usually possess paired limbs with toes at their distal extremities. The more primitive amphibians spend their lives in the water breathing by means of gills, but specialized forms, like the frogs and toads, are only strictly aquatic during larval development and spend more or less time on land as adults. Thus, though amphibians are typically aquatic, the group as a whole is migrating to the land, and a few species have attained a truly terrestrial life. This is perhaps the point of greatest interest in connection with amphibians—some live much like fishes, others start in life as fish-like tadpoles and later become terrestrial.

There are three orders in the class Amphibia:

1. Apoda. Degenerate, limbless amphibians which live only in tropical countries. They look much like earthworms and, like them, burrow about underground. The eyes are very degenerate and the skin contains skeletal plates.

2. Caudata. Salamanders; aquatic or terrestrial amphibians which have tails when adult.

3. Salientia. Frogs and toads, which are without tails in the adult condition.

In order to emphasize the differences between primitive and specialized amphibians, representatives of two orders will be considered—an aquatic salamander (*Necturus*), and the common garden toad (*Bufo*).

THE MUD-PUPPY, *Necturus maculosus* Rafinesque

North America is fortunate in having this primitive salamander within its boundaries, mostly through the Great Lake Region. Necturus lives among the submerged rocks near the shores of lakes and streams, and is commonly, though incorrectly, called a "lizard" by fishermen.

Self-maintenance.—Necturus (Fig. 97) hunts at night for crayfishes, insects, worms, fishes and their eggs (C). Its eyes are small, poorly developed, and of little or no

FIG. 97.—The Mud-puppy, *Necturus maculosus*. A, young; B, swimming; C, catching a crayfish. D, eggs; E, larva with yolk sac nearly absorbed.

value for procuring food, but the sense of taste is acute and generally distributed in the skin. Necturus is able to discover small animals concealed in the crevices between rocks, and devours them whole. The jaws are armed with double rows of fine pointed teeth for holding the struggling victims of nocturnal forays. Necturus usually creeps about slowly, using the small legs, but when so inclined may

swim skillfully by making undulatory movements with its muscular body and tail (B).

The digestive system is much like that of other vertebrates, consisting of a mouth, pharynx, œsophagus, stomach, intestine, liver and pancreas. There is a bladder opening from the ventral wall of the intestine which receives the urine brought by ducts (ureters) from the kidneys. The heart has three chambers, a ventricle and two auricles. One auricle is filled with "impure" blood from the larger veins, the other receives aerated blood from the gills. The structure of the heart is such that, though both kinds of blood enter the ventricle and are pumped out together, the freshest blood goes to the head and visceral organs, while most of that charged with waste products reaches the gills. The gills are tufts of filaments through which waste gases are exchanged for oxygen. Slender lungs are also present and if the water becomes stagnant, Necturus may go to the surface and gulp in air.

Self-protection.—The mud-puppy is protected in many ways from its enemies. It is acceptable food for water snakes and other predaceous animals, but usually escapes through its nocturnal habits and protective coloration. It may, like other cold-blooded vertebrates, change its colors somewhat to suit the background on which it rests. All amphibians have poison glands in the skin, and the bitter secretion from these makes the mud-puppy distasteful to many animals which might otherwise feed upon it. If attacked or captured, Necturus will bite viciously, but the wounds inflicted are not poisonous, as many fishermen believe.

If Necturus loses a leg or a piece of its tail, the lost parts are regenerated after a time. The process of regeneration and growth in salamanders has been the subject of careful experimental study, and some fundamental facts have been discovered. For example, if the portion of an embryonic salamander eye known as the optic cup is removed and grafted almost anywhere under the skin of the head, a

complete crystalline lens is formed in the new situation. The presence of optic tissue stimulates the ectoderm to form a lens. Metabolic processes have much more latitude in fishes and amphibians than in warm-blooded vertebrates —where powers of regeneration are limited and growth processes are not open to much modification.

The mud-puppy is often attacked by parasites and infectious diseases. Fish-mould (*Saprolegnia*), a fungus which enters the body through slight abrasions and destroys the tissues, is the most important of these. Another common parasite is a minute trematode worm which attaches itself to the gills and sucks blood.

Necturus remains active beneath the ice throughout the winter, in this respect resembling fishes and some other aquatic animals which dwell in lakes and rivers. The temperature of the water may be low, but never falls below freezing, and conditions are, therefore, stable enough to permit a sluggish, but not wholly inactive, existence.

Race Preservation.—Amphibians are always dicœcious, but Necturus males are much like the females in appearance. Though animals are usually found in pairs in autumn, egg laying takes place in May and June. Each female deposits a number of eggs enclosed in little cases and attached by stalks to the under side of stones (Fig. 96, D), logs, tin cans, and other objects in the water, where they pass through the usual developmental stages (Fig. 65). The whole egg separates during cleavage (Fig. 115), but at one pole the accumulation of yolk retards cell-formation somewhat and the cells are, therefore, larger there. Instead of forming on one side of the egg, as in fishes, the embryo develops entirely around the yolk-containing portion, but there is a large yolk sac which protrudes from the ventral side of the developing embryo until absorbed (Fig. 97, E).

The young (Fig. 97, A) are striped along the back, and thus differ from the adults. They live among the water plants alongshore where they are effectively concealed by

their coloration. Necturus is sometimes called a "mature larva" and it may be properly compared with the well-grown tadpoles of many other amphibians. The gills are functional, but lungs have developed and the sexual organs are mature.

GENERAL REMARKS ON CAUDATA

The tailed amphibians show an interesting transition from aquatic to terrestrial habits. *Necturus* is entirely aquatic, possessing well-developed gills and very small lungs. *Siren*, which lives in the rivers of the southeastern United States, starts in life as a tadpole, partly loses its gills, and then has them enlarge again to functional size. *Cryptobranchus* is aquatic throughout life and breathes by means of gills which, however, are covered. Water for respiration enters the mouth and passes out through a pore on either side of the neck. *Ambystoma* is the common "tiger" salamander throughout the eastern and central United States. It is of particular interest because certain species in the genus show pædogenesis; that is, they become sexually mature while in the larval state, and an individual with gills may lay fertile eggs. As a rule, however, the adults are found in damp situations on land, and are often encountered under stones and logs, or in cellars. *Diemyctylus* is the beautiful vermilion-spotted newt of New England. Its life cycle requires several years for completion. During the first three years it is a green aquatic larva; then migrates to the land and becomes bright orange with vermilion spots. After a period of terrestrial life, the newt returns to the water, becomes green in color, and leads an entirely aquatic existence while breeding. *Desmognathus* is a truly terrestrial salamander which has no gills or lungs, but breathes by gulping air into the throat, which is very vascular. After becoming mature it returns to the water to breed. *Plethodon*, the red-backed salamander, does not enter the water even to

breed. It lays its eggs in little packets under logs and stones, and guards them until they hatch.

Considering the ontogeny of salamanders and the habits of various existing species, the law of biogenesis (page 60) indicates that they are as a group migrating from water to land. Nearly all begin life as a fish-like tadpole which breathes by means of gills, but in the adult condition there are all degrees of adjustment to terrestrial life.

THE COMMON TOAD, *Bufo americanus* Le Conte

Salientians in general are highly specialized. They start in life as tadpoles, but are tailless when mature and show many evidences of specialization. The toad is a typical representative. It is specialized in its marked adjustment to terrestrial life, but shows aquatic affinities in its habit of annually returning to the water to breed.

Self-maintenance.—A toad obtains food by means of its flexible tongue. There is a gland in the roof of the mouth which forms a very sticky secretion. When the tongue is suddenly protruded, it adheres to the food and draws the morsel back into the mouth (Fig. 98, B). The tongue is extended by suddenly filling a lymph space at its base. Toads depend chiefly on their sense of sight for procuring food and will snap at almost any moving object. This habit is general among salientians, and is taken advantage of by fishermen who use a bright-colored rag as bait for catching frogs. A toad has no teeth and insects captured are swallowed at once without any preliminary chewing. If some distasteful object is snapped up, it is quickly spit out, even after it has passed down into the stomach.

The food habits of toads make them of considerable economic importance. A recent estimate by a scientific expert in the Department of Agriculture places the annual value of a single individual in a garden at $19.44. In cities also a toad may do great good by feeding at night on the insects about street lights.

A toad has two methods of locomotion—hopping and walking. The whole body is adapted structurally for progression by leaping, and in moving about that method is usually employed, but at close quarters a toad is able to stalk its food as cautiously as a lynx. An active insect, however, is often secured by leaping upon it from a distance of two or three feet.

FIG. 98.—Salientia. A, Wood frog and green frog; B, the garden toad, *Bufo americanus*—male singing, catching fly, egg string, tadpoles; C, tree frog and cricket frog.

The metabolic processes of a toad are much like those of other cold-blooded vertebrates. The digestive and excretory organs resemble those of Necturus. The circulatory and respiratory systems are, however, adjusted to life on land. The blood-vessels which supply the gills during larval life are diverted to the lungs and skin when terres-

trial habits are assumed (Fig. 105, B). Most salientians breathe as much through their soft moist skins as through the lungs. On this account they are able to endure prolonged submergence; the blood being aerated through the skin from the surrounding water.

Self-protection.—Though toads have bitter, poisonous secretions in the skin, they are eagerly eaten by snakes, owls, and other animals. They escape from many enemies, however, by doing most of their hunting in the early morning or at twilight, and hiding in their holes during the day. Hopping is a somewhat erratic method of locomotion and toads are hence often able to elude a pursuer. Their colors also render them relatively inconspicuous, and may change somewhat to match different backgrounds.

Salientians have less power of regeneration when adult than salamanders. If a foot is lost, it does not grow again, but the leg remains a deformed stump. The tadpoles of frogs and toads are rather remarkable for their ability to replace lost parts, and continue to grow after serious injuries. Eight- and ten-legged frogs, two-tailed tadpoles, and other monstrosities have been produced by splitting embryonic structures. It is also possible to form composite tadpoles by grafting parts of different individuals together.

On account of their terrestrial life toads cannot remain active during the winter like the strictly aquatic amphibians. At the approach of cold weather, they burrow into the ground below frost and remain in a torpid condition. During hibernation metabolism is very slow and many activities are dormant; a toad may be cut in pieces without giving any sign of life.

Race Preservation.—Toads show one great advance in complexity of mating instincts when compared with a salamander—they make use of sounds. In order to insure the continued existence of any race of animals, the eggs must be fertilized and any adaptation which tends to make this more certain is therefore desirable. In spring when the male toads enter the ponds and utter their shrill notes

(Fig. 97) they are giving notice to every mature female within hearing of their presence and ability to fertilize eggs.

During mating the male clasps the female with his front legs and squeezes the eggs from her body. As eggs emerge, sperm is discharged over them and fertilization takes place in the water. The clasping reflex of the male is controlled in the spinal cord and is very strong during the breeding season. A male while clasping may have his head removed and the whole of the body behind the front legs cut away without letting go his grip; the front legs continue to hold on until they die.

The eggs of toads are laid in long strings of jelly which protect them. They are usually deposited at night and a single female produces from four to ten thousand each spring. Tadpoles hatch from the jelly about four days after the laying of the eggs. At first they have short tails and a protruding yolk sac on the belly. They have no mouth, but cling to aquatic vegetation by means of a sucker beneath the head until the yolk is absorbed. On the tenth day the mouth is well formed and the tadpoles begin to feed on water plants. The gills, which are feathery tufts on the sides of the head at the time of hatching, are gradually covered by the backward growth of a membrane (the operculum) from the head, and a well-grown tadpole has only one exit for the respiratory water through a pore on the left side.

The legs grow out as little buds which later develop toes at their distal ends. The front pair are formed inside the opercular cavity and do not appear externally until the tadpole is nearly ready to leave the water. As a tadpole grows older it shows a greater fondness for animal food, and the alimentary canal accordingly grows shorter. It is a general rule among animals that vegetable food is associated with great length of digestive tract, and carnivorous diet with a short enteron. The teeth in the tadpole also change and the earlier chitinous exoskeletal plates associ-

ated with plant food are lost (in frogs they are replaced by bony teeth).

Tadpoles hatched from eggs laid about the first of June will transform into young toads about the middle of July. As a tadpole nears the end of its sojourn in the water, the gills grow smaller and lungs are developed. Frequent trips are made to the surface of the water and, after the front legs become functional, much time is spent on land, just out of the water. The tail becomes soft and flabby, grows gradually shorter, and finally, some fine day, shrivels up completely. Then the tadpole is no more, but a little toad hops away to hide in the grass and hunt for small insects. Often minute toads migrate from ponds in great armies after a rain, and ignorant people therefore believe that they rained down. The delicate creatures are not yet fully adjusted to life on land and are unusually active when the air is moist.

If we apply the Law of Biogenesis to the development of a toad, it leads to the same conclusion as in the case of a salamander. The ancestors of amphibians were aquatic fish-like vertebrates which later developed lungs and left the water. Most salientians are more markedly terrestrial than caudate amphibians, and show more striking adaptations for life on land. Some species even live in deserts where they pass the dry season in a condition of æstivation, but most amphibians are limited to rather moist situations on account of their soft skins. They are for the most part confined to shady nooks in the shelter of vegetation and seldom hunt in the glare of a noonday sun. They are not as well adapted to the land as reptiles, birds, and mammals.

GENERAL REMARKS ON SALIENTIANS

The commonest frogs throughout the United States are the leopard frogs, *Rana pipiens,* and related species. The green frog, which is often brown or mottled, agrees with the bull frog in possessing very large tympanic mem-

branes, is also quite common (Fig. 98). The largest and most aquatic species are the bull-frogs; some individuals attain a body length of seven or eight inches. The wood frogs are adapted to terrestrial life, and may spend a large part of the year at considerable distances from water.

The tree-frogs (*C*) usually live among vegetation. They have sucking discs at the tips of the toes, which enable them to climb with ease. They also possess remarkable ability to change their colors to match the surroundings. The little brown cricket frog of the United States is a degenerate among tree-frogs which spends most of its life in or near the water and has only rudimentary discs at the ends of its toes. A very specialized tree-frog in Java is able to sail from tree to tree by using the spread webs between the toes. It does not go to ponds to breed, but makes a suspended nest inside a rolled leaf.

CHAPTER XXIV

SUBPHYLUM VERTEBRATA, CLASS REPTILIA

Reptiles are cold-blooded, scaly vertebrates, which breathe by means of lungs. The body is never soft and slimy as in amphibians, but covered with a dry skin which conserves the moisture within and permits existence on land without danger of dessication. The representatives of this class are typically terrestrial; even the marine turtles and sea snakes, which spend their lives in the open ocean, always return to the land to breed. With the exception of the snakes, limbless lizards, and certain other forms in which the legs are somewhat degenerate, reptiles have claws at the tips of the toes. There are four orders of living reptiles and six times as many which existed in the past but are now extinct. The orders of existing reptiles are as follows:

Order 1. Squamata. Body elongated and covered with small scales, anus slit-like and extending across the body.

Suborder 1. Sauria. Limbs, eyelids, and external ear opening usually present. Lizards.

Suborder 2. Serpentes. Limbs, eyelids, and external ear opening absent. Snakes.

Order 2. Rhynchocephalia. Represented by a single species, *Sphenodon punctatum*, a reptile resembling the lizards, but possessing a large eye-like organ in the center of the forehead. This animal is found only in New Zealand.

Order 3. Testudinata. Body short, broad, and enclosed between two (dorsal and ventral) shields. Turtles, tortoises.

Order 4. Crocodilia. Body elongate and adapted to aquatic life; limbs present; anus a longitudinal slit. Alligators, caimans, crocodiles.

Before discussing the different orders, the activities of a little lizard which inhabits the Eastern United States will be considered in detail.

THE BLUE-TAILED SKINK, *Eumeces quinquilineatus* Linnæus

Self-maintenance.—This little lizard hunts among vegetation for insects, which constitute its principal food. It sometimes eats bird's eggs, young field mice, or other animals of suitable size. It is well fitted to seek and capture food. Its sight is very acute. The sense of taste is also well developed, for ill-flavored substances are often spit out after being taken into the mouth. The claws on the ends of the toes enable the skink to run up and down the trunks of trees with great swiftness. Though the mouth is provided with teeth for holding prey, the food is not chewed, except enough to kill it, before being swallowed.

The digestive organs of the skink resemble those of other vertebrates, but the respiratory, circulatory and excretory systems are better adjusted to terrestrial life than those of the land amphibians. There is no respiration except through the lungs; the structure of these organs and their associated parts is more specialized than are those of an amphibian. There are little chambers on the inner wall of the lungs which increase the surface exposed and no large branches of the blood-vessels supply the skin. Air is drawn into and expelled from the lungs largely by movements of the ribs, whereas frogs and toads have no ribs, but force air in by gulping movements of the throat. The chief excretion product in a reptile is uric acid, which is thrown off as a solid—in fact, is insoluble in water—and is therefore more desirable for a terrestrial animal (which needs to conserve its water) than urea, which requires liquid for its elimination.

As the skink grows the "skin" is shed from time to time. The whole epidermis does not come away in one piece, as in many snakes, but sloughs off in patches. Preparation is made in the skin before shedding occurs and a softening takes place in a particular layer of the

epidermis, so that the outer part may be pushed off without injuring what remains.

Self-protection.—The skink is very shy and very swift. When basking in the sun or chasing insects, it is always ready, if danger threatens, to scuttle away to some safe retreat which it knows about. It hunts entirely by day and when inactive usually hides in some crevice with only its head protruding. The watchful eyes give warning of any disturbance, and the skink is hard to catch. If grasped by an enemy, however, it is still not beyond hope

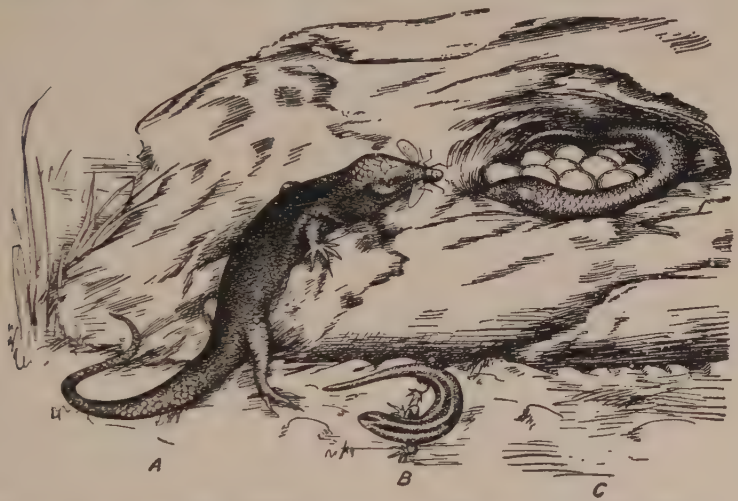


Fig. 99.—The Blue-tailed Skink, *Eumeces quinquilineatus*. A, adult male catching insect; B, young; C, female with her eggs in a cavity in a rotten log.

of escape. The tail may be cast off and left with the enemy while its owner runs away. Most lizards shed the tail very readily and no permanent harm results, for it grows again after a time.

A skink's colors change with age. In youth the body is jet black with five longitudinal yellow stripes on the back and a bright blue tail. After three or four years the colors become dull, and a mature individual may lose its stripes completely. An adult male has a bright copper-red head and a brown body; a female is usually brown with light

longitudinal stripes. In general the colors are suitable for the activities of different kinds of individuals, and skinks are therefore protected from enemies at all ages.

There is one defect in the skink's means of defense. A reptile of any kind cannot remain active at low temperatures. During cool weather, therefore, a dormant skink, if its hiding place is discovered, makes a fine meal for any prowling warm-blooded animal.

Race Preservation.—Skinks, like other reptiles, are of separate sexes. In the species under discussion the mature males are easily recognized by their bright red heads. In the northern states they mate with the females in June, fertilization taking place within the female's body before the shell is formed about the eggs. This is an improvement over the method of fertilization prevalent in amphibians, where the sperm and egg cells are usually discharged into the water. When the eggs are laid, early in July, segmentation has already begun. They are deposited in little cavities in the rotten wood of old stumps, and the mother remains with them until they hatch (Fig. 99, C). In August the young skinks leave the nest and start out for themselves.

Though the development of reptiles is similar to that of amphibians, it shows greater specialization for terrestrial life. A skink, or any other reptile, always lays its eggs on land, whereas amphibians usually deposit theirs in water. The gills in an embryo skink are absorbed long before the egg hatches and are never functional as breathing organs. A lizard also shows greater ability to adjust itself to its surroundings; in other words—is less stupid than a frog or toad, and even has some glimmerings of intelligence. If a skink encounters a distasteful insect, like a hornet or an ill-flavored caterpillar, it tries to eat it the first time, but after that avoids all insects of similar appearance. It can learn in its dull way that a certain color or form is associated with disagreeable experiences.

GENERAL REMARKS ON THE ORDER SQUAMATA

Lizards are clearly more generalized animals than snakes. Most of them possess four well-developed legs with toes, though there are a few which agree with snakes in lacking any external indication of appendages in the adult condition. Snakes are specialized in the absence of appendages, the structure of their jaws, and in other particulars. Yet, despite the divergences between snakes (Serpentes) and lizards (Sauria), their fundamental plans of structure are so similar that they are placed by systematic zoologists in one order.

It cannot be said, however, that many lizards are not specialized; some, indeed, are highly adapted to peculiar modes of life. The limbless species all burrow, and are seldom seen above the surface of the ground. The flying-dragon, *Draco volans*, has thin lateral expansions on the body which are supported by the ribs and furnish enough surface so that the animal can sail from tree to tree. The chameleons have prehensile feet and tail, hence are able to climb with great sureness, and their remarkably extensible tongue enables them to snap up insects among the trees. Their unusual ability to change the colors of their skins is also noteworthy. The "horned toads" are adapted to life in the desert. They are spiny, burrow to escape extreme heat or cold, and have other adaptations which enable them to live in arid localities.

The largest lizards in America are the iguanas, which range from the southern United States southward. They attain a length of six feet, and are often eaten by man. They eat vegetation, insects, bird's eggs, and animals up to the size of a half-grown rabbit. Through the southern states the little anoles are very common among plants. They are easily tamed and are often sold by curio dealers. The only poisonous lizards known live in the southern United States and Mexico. These Gila monsters (*Heloderma*) are sluggish but powerful creatures with bands of

bright red and black around the body. They have a poisonous spittle and bite viciously when molested. When their bodies are well nourished the tails become swollen with stored fat, and they can then live for some time without food.

Snakes are not only without limbs but show various other adaptations correlated with their slender forms. One lung is usually rudimentary, the visceral organs are peculiarly arranged, and there is no urinary bladder. The two halves of the lower jaw are connected by an elastic ligament, and are loosely fastened to the skull. This arrangement makes it possible for a snake to swallow animals which greatly exceed its own body in diameter. Snakes move by waving the ventral scales backward and wiggling the body. Muscles lead from the scales to the ribs, which help materially in locomotion. There is great variation in the size of snakes—a python may have a length exceeding thirty feet and weigh over three hundred pounds; some of the burrowing snakes are less than six inches in length and no thicker than a goose quill.

Snakes may be viviparous or oviparous; that is, the young of some species are born and those of others hatch from eggs. The garter snakes bear their young in such condition that they are soon able to shift for themselves. The milk snake lays eggs in holes in the ground.

Though there are many venomous snakes, the harmless species greatly outnumber them. Of the one hundred and eleven species in the United States less than twenty are poisonous. The venomous snakes have a poison gland on either side of the head which is connected with a grooved or hollow fang in the mouth; the non-poisonous species have the jaws armed with sharp backwardly directed teeth which hold the food and help in swallowing. There are two types of poison fangs—grooved and tubular. The former is more primitive, and the hollow type has apparently been derived from it by a closing over of the groove. The grooved fang is usually fastened immovably

to the jaw; but the hollow fang is folded against the upper jaw when not in use and becomes erect when the mouth is opened to strike. Snakes continually protrude the forked tongue when they are moving about and this habit has often led to the belief that the tongue is the fang or "sting," an idea which is of course erroneous.

In the United States there are only five kinds of poisonous snakes: coral snakes, water moccasin, copperhead, rattle snakes, and opisthoglyphs. Two species of coral snakes (*Elaps*) are found in the south. They are banded with red, black, and yellow, and have grooved fangs. Four species of opisthoglyphs are found along the southern border of the United States. They are small snakes with grooved fangs which are set far back in the mouth. They cannot readily inject poison by striking quickly at an animal, but must take the prey into the mouth to kill it. The other three types range farther north, have hollow fangs, and belong to the group of venomous snakes known as pit vipers. In these there is a well-defined depression on either side of the head between the nostril and the eye. The water moccasin or cotton-mouth (*Ancistrodon piscivorus*) is a semi-aquatic serpent which frequents the lagoons and sluggish waterways in the southeastern states. It averages about four feet in length but may reach six. The body is very stout and heavy, with an abruptly tapering tail and a chunky, ugly head. The copperhead (*Ancistrodon contortrix*) is found east of the Mississippi River from Massachusetts to Florida. It frequents forests and plantations, hiding among fallen leaves which it closely resembles in color. There are nineteen species of rattle snakes and the majority of them are found in the United States and Mexico. The diamond-back (*Crotalus adamateus*) of the southeastern states is the largest and most deadly of our native serpents. The rattle is an unique organ among snakes. The little bells which compose it are formed each time the skin is shed, and are not closely indicative of the snake's age.

ORDER 3. TESTUDINATA (CHELONIA)

The turtles and tortoises (Fig. 100) are clearly distinguishable from all other reptiles by the beak-like, toothless jaws and by the shell covering the body. The turtles are aquatic, some species never going on land except to breed, and the tortoises are terrestrial. All chelonians lay eggs, which are buried in shallow excavations on sandy beaches

FIG. 100.—Testudinata. A, the common painted turtle; B, Soft-shell turtle; C, Snapper; D, turtle eggs; E, terrapin.

or on hillsides (D). Their food varies greatly: the giant tortoises of the Galapagos Islands subsist on cactus; certain marine turtles eat molluscs, fishes, and seaweeds; the fresh-water species feed upon vegetation, molluscs, crayfishes, insects, fish, frogs, snakes, birds, mice, rabbits, etc.

In the interior of the United States there are a number of species of chelonians. The snappers (C) are rough-backed ferocious animals. The common species in the north (*Chelydra serpentina*) does not weigh over forty pounds, but the southern alligator snapper (*Macrochelys*

lacertina) reaches a hundred and forty. The painted, or "mud," turtles (A) are the commonest chelonians throughout the country and may often be seen sunning themselves on logs along swampy shores. The soft-shelled turtles (*Platypeltis*, B) are remarkable for their leathery covering and the extreme length of their necks.

Through the middle states Blanding's turtle is common along ponds and streams. It is a "semi-box" turtle; that is, there is a hinge across the ventral part of the shell, so that it may be closed over the retracted head and front legs. It spends more time out of water than most turtles, and is often found wandering in fields or woods. In the southeastern states lives the terrapin, *Terrapene carolina* (E), which is a true box tortoise. It has the ventral plate so hinged that it completely closes the shell. The terrapin lives in woods and does not enter the water; feeding on berries, earthworms, and insects. There are a number of species of giant tortoises inhabiting islands of the Pacific and Indian Oceans. They never enter the water, and feed on cacti, grass, leaves, and fruits.

Along the shores of warm seas the large marine turtles are regularly caught for the market, being harpooned in the open ocean or captured while ashore for breeding. The loggerhead turtle may reach a length of four feet and weigh five hundred pounds. The green turtle is somewhat smaller (150 pounds), but is more highly esteemed for the table. Almost any turtle is suitable as food for man, but the marine turtles and tortoises are most generally used. The Bureau of Fisheries has demonstrated by recent experiments that the terrapin may be reared successfully for the market on small farms. Most of the fresh-water turtles do considerable damage by destroying fishes and small aquatic animals which might serve as fish food.

ORDER 4. CROCODILIA

The crocodiles and their relatives resemble the lizards in form, but attain a much greater size and are adapted to

aquatic conditions. The nostrils and ears can be closed, and there is a valve at the back of the mouth so that food may be captured under water without danger of filling the lungs. The teeth are set in bony sockets, and there are bony plates beneath the scales in the skin. The heart has four chambers (two auricles and two ventricles) thus resembling the condition found in birds and mammals.

The only crocodilians in the United States are the alligator, *Alligator mississippiensis*, which lives in the rivers emptying into the Gulf of Mexico, and the American crocodile, *Crocodilus americanus*, in southern Florida. The alligator may attain a length of twelve or fourteen feet. During the breeding season the males bellow like bulls and give off a penetrating odor from two musk glands in the lower jaw. Nests are constructed by heaping mounds of rubbish in swampy places and eggs are deposited in them. The American alligator is very shy, but some Indian and African crocodiles attack man.

GENERAL REMARKS ON REPTILIA

Without much doubt reptiles arose during evolution from aquatic salamander-like ancestors. This seems probable both from the palæontological records and the embryological changes in living forms. Fossil remains in the stratified rocks show that the first vertebrates on earth were fishes, and that amphibians preceded reptiles. A modern reptile during its embryology is at first fish-like, then salamander-like, and in both stages possesses gill clefts which never function as breathing organs but are lost before hatching takes place.

Modern reptiles are for the most part truly terrestrial animals, but are handicapped to some extent by the fact that they are cold-blooded. They are on this account confined to the warmer parts of the earth, whereas the birds and mammals may invade the frigid regions. Reptiles have mastered air-breathing and water conservation, so

that they may live on land without danger of drying up and even dwell in deserts, but have never attained to temperature regulation like the "warm-blooded" animals.

During past ages, however, the reptiles were a mighty race, and at one time ruled the earth. They were specialized along diverse lines and during early tertiary times were the dominant animals in most of the available habitats (Fig. 101). Icthosaurs, plesiosaurs, crocodiles, and mososaurs were admirably fitted to prey upon the smaller

FIG. 101.—Restorations of fossil reptiles. (*Adapted from Knipe and Lucas.*) A pterodactyl soars through the air, two dinosaurs are walking along the shore, and a mososaur swims in the water.

animals in the ocean, before there were whales or dolphins. The empire of the air was ruled by great pterosaurs, which were somewhat like birds in form but possessed teeth and long tails. They had, like birds, many adaptations for aerial life—such as wings and hollow bones. One species could spread its wings about twenty feet. The land was inhabited by giant dinosaurs and other reptiles, some exceeding a hundred feet in length. There was great

diversity in habits and some species resembled mammals in structure. There were carnivorous dinosaurs which looked much like great lizards or kangaroos; and herbivorous species like rhinoceri and buffaloes. The reptiles of past ages occupied the places now taken by birds and mammals and had many of their adaptations.

But the great abundance of reptile life which once dominated the earth has now gone forever. Only a few stragglers remain from those which at one stage in the earth's evolution were the best animals that had been produced. Nature has since brought forth better living mechanisms. But the reptiles did not live in vain, for evolutionists tell us that some of the extinct forms doubtless gave rise to the birds and mammals.

CHAPTER XXV

SUBPHYLUM VERTEBRATA, CLASS AVES

Birds differ from all other vertebrates in possessing feathers, though the scaly feet suggest relationship to reptiles. Certain extinct species possessed teeth and had separate toes ending in claws on the front limbs, but all modern birds have the toothless jaws covered with a horny beak and the digits of their wings are more or less rudimentary. Birds, like mammals, are "warm-blooded"—that is, are capable of maintaining a constant body temperature.

There are two subclasses of Aves:

Subclass 1. Archæornithes. Extinct birds having toothed jaws, a long lizard-like tail composed of separate vertebræ, and three separate, clawed digits on each of the fore limbs.

Subclass 2. Neornithes. Extinct and modern birds in which the terminal vertebræ of the tail are fused to form a pygostyle, or "plowshare" bone; the jaws are toothless, except in some extinct species; the bones of the fore limb are more or less fused and reduced in size.

SUBCLASS 1. ARCHÆORNITHES

This group of birds is known from only two specimens and a separate feather, found in the lithographic slate at Solenhofen, Bavaria. All these fossils are referable to a single species, *Archæopteryx lithographica* (Fig. 102). This bird was about the size of a crow. It had a long flexible tail with feathers along either side, and the wings bore three free digits, each with a claw, while the hind legs had four toes, like those of modern birds. The jaws were armed with a row of strong teeth set in sockets.

Though this curious flying animal, preserved as a fossil for our inspection from Jurassic times, has characteristics

of both reptiles and birds, as judged by existing representatives of those groups, it is classed with the latter and is looked upon as the most primitive known bird. Archæopteryx had feathers, and in this respect differed from all reptiles, living or fossil. It is about as nearly a "missing link" as science may reasonably expect to find when the imperfection of the fossil record is considered, and its

FIG. 102.—*Archæopteryx* (A) and *Hesperornis* (B), two extinct toothed birds. (*After restorations by Knipe and Lucas.*)

structure is believed to indicate, with other evidence, that birds were evolved from reptilian ancestors.

SUBCLASS 2. NEORNITHES

The birds in this group are characterized by having several vertebræ at the tip of the tail fused to form a "plowshare bone" which acts as a support for the large tail feathers. The wing bones are reduced and more or

less united; there are never more than two free digits with claws, and usually none. Four orders of fossil birds are placed in this subclass, as are seventeen whose representatives live today. Space will not permit the discussion of all these; they will, therefore, as a matter of convenience be divided into three groups: (1) primitive fossil birds; (2) recent flightless birds; (3) recent flying birds.

The fossil Neornithes had some very peculiar features: *Hesperornis regalis* (Fig. 101) was a flightless bird about four feet long, adapted for swimming and diving. It had teeth set in grooves in the jaws; the sternum was without a "keel" for the attachment of wing muscles, and the strong hind feet were webbed for swimming. The remains of this great diver have been found in the Cretaceous deposits in Kansas. In the same region the remains of other aquatic birds which had keeled sterna and jaws bearing teeth set in sockets have been discovered.

The elephant-birds (*Æpyornis*, etc.) and the moas (*Diornis*, etc.) probably became extinct within the past five hundred years. The former were great flightless creatures which lived in Madagascar. The eggs of Æpyornis have occasionally been dug up along the seashore; some of them are over thirteen inches long and have a capacity of a couple of gallons. Over twenty species of moas formerly lived in New Zealand. They were unable to fly and possessed enormous hind limbs adapted for running. Some were as small as turkeys, while others stood ten feet in height. Probably the early human inhabitants of New Zealand exterminated these birds, for remains are found in caves and in ancient refuse heaps.

Among recent birds which fly but little or not at all, the kiwis (*Apteryx*) of New Zealand are the most striking. They are about the size of a hen and have a very long beak which they use as a probe in seeking worms underground. The wings are very degenerate, being represented by small bones which do not appear outside of the body; tail feathers are wholly lacking. The penguins (order *Impennes*) of

which about twenty species are known, are confined to the Antarctic regions. They live the greater part of the time in the open ocean where their short wings (inadequate for flight) are used for swimming. When on land, penguins walk erect or, if in haste, slide along on the belly. They nest on land in great colonies during the Antartic summer which is colder than winter in the United States. Several birds often coöperate in incubating the eggs and caring for the young. The cassowaries, emeus, ostriches, and rheas are large running birds with small wings and large, powerful legs. The ostriches, or camel-birds (*Struthio camelus*), live in the desert regions of Africa, and travel about in groups. These are the largest living birds, some individuals attaining a height of eight feet and weighing over three hundred pounds. They are very shy and flee swiftly when approached; but do not hide their heads in the sand, as is commonly believed. Ostrich farming is now a well-established industry in South Africa and certain parts of the United States. A domesticated ostrich will yield fifteen or twenty dollars worth of plumes each year. The utilization of such feathers is desirable, for plucking causes the ostrich little inconvenience and the use of the plumes saves the lives of many wild birds which might otherwise be slaughtered on the altar of fashion. The tinamous are birds inhabiting Mexico, Central and South America. They resemble partridges in appearance, but fly very little.

The flying birds are divided into ten orders. The loons and grebes (*Colymbiformes*) are strong flyers but are chiefly remarkable for their ability to swim and dive. A loon can stay under water several minutes, and travel a quarter of a mile while submerged. The albatrosses, fulmars, shearwaters, and petrels (*Procellariformes*) are gull-like marine birds with tubular nostrils and long slender wings. They are excellent flyers and nest in great colonies on oceanic islands. The stork-like birds (*Ciconiiformes*) include the tropic birds, cormorants, anhingas, pelicans, herons, bitterns, spoonbills, storks, ibises, flamingoes, etc. Most of

these birds have long legs, slender necks, elongated bills, and feet fitted for wading or swimming. The geese, river-ducks, sea-ducks, fish-ducks, swans, and screamers (*Anseriformes*) have webbed feet and are aquatic in their habits.

Hawks, eagles, vultures and secretary birds (*Falconiformes*) are the true birds of prey. The owls, which in the popular mind are associated with them—probably as much because of their food habits as for any other reason—belong to a different order. All the birds of prey have very strong talons and hooked beaks, which are used for catching and killing animals for food. The owls, together with the kingfishers, hummingbirds, goatsuckers, woodpeckers, and a few other rare forms are placed together in the order *Coraciiformes* because of certain anatomical similarities. Owls are generally nocturnal, but are able to see more or less during the day. Their great expanse of wing, together with a peculiar frilling of the feathers, enable them to fly with a quietness remarkable in such large birds. The hummingbirds are the smallest of the class Aves, the largest being less than eight inches long, and the smallest, two and three-eighths inches. Over four hundred species are known in America, but only one is found throughout United States. They are nearly all of gorgeous metallic colors, changing in different lights. The woodpeckers are remarkable for their peculiar beaks, extensible tongues; the stiff tail and peculiarly arranged toes both function in climbing. The rails, cranes, and coots (*Gruiformes*) are marsh birds with long legs for wading or with lobate feet for running over aquatic vegetation. Snipes, plovers, curlews, and jacanas are related to the gulls, terns, auks, and pigeons (*Charadriiformes*). The snipes and their near relatives are waders; the gulls are strong flyers and live largely on fish; the auks are sea birds with very heavy beaks, and nest in holes in the ground; the gentle pigeons and doves are widely distributed, three hundred species being known. The cuckoo-like birds (*Cuculiformes*) include the true cuckoos, parrots, and a number of tropical birds. The cuckoos are insect

eaters, and are chiefly known from the habits of the European species, which deposits its eggs in the nests of other birds. Parrots live largely on fruits and seeds. Only one rare species, the Carolina Paroquet, occurs in the United States, and it is altogether probable that this has become extinct during the last few years.

Most of the familiar small birds belong to the order *Passeriformes*, which includes almost half (7000) of the known species of birds. There are sixty-four families in this important order—the finches, flycatchers, vireos, thrushes, wrens, blackbirds, jays, swallows, warblers, and many others being included. Passerine birds are usually of small or medium size, but are the most highly organized of the class Aves. The feet are fitted for perching, and representatives of the order are often called "perching birds." A familiar example is the American robin, which will be considered in some detail. This bird is not closely related to the European "robin red-breast," which belongs in an entirely different family. It is familiar to everyone in North America because of its trusting ways and the readiness with which it adjusts itself to the changes accompanying the advance of civilization.

THE AMERICAN ROBIN, *Planesticus migratorius* Linnæus

Self-maintenance.—The robin eats caterpillars, insects, earthworms, and other small animals. Everyone has seen it straining and tugging to pull a fat worm from the lawn. There has been some dispute among students of bird foods as to whether the robin is beneficial or injurious to man. Barrows says: "There is no question that the robin sometimes does a large amount of good in its consumption of insects, especially by eating cutworms and grasshoppers; it must be remembered, however, that the major part of its insect food is taken from the ground and that hence the robin is a factor of small importance in limiting the activity of the spanworms and other caterpillars which defoliate our fruit and shade trees. It also eats large numbers of

insects which at best are not harmful, and which possibly may be beneficial." Forbes states that, "while the robin is not so precious that we need make it an act of sacrilege to show him the muzzle of a gun in a cherry orchard—on the other hand it would be an enormous blunder to wage ourselves, or to permit others to wage, any general or indiscriminate war against him."

The robin depends for the most part on its acute vision and agility to secure food. Its sharp eyes are quick to spy out any lurking insect in a garden, and its horny beak is an excellent organ for capturing such morsels, for it is impervious to bites or stings. Birds are handicapped somewhat in feeding by the lack of claws or other seizing organs on the front limbs; but this is compensated for by the great quickness which is associated with the use of the wings for flight, and by the great flexibility of the neck.

The feathers are admirably adapted for flight; being light, yet with broad expanse; flexible, but stiff enough to resist the air. The small barbs on either side of the main shaft are provided with minute hooked barbels which bind them together so as to make a broad flat surface; this may be broken up repeatedly, yet on being smoothed over again will be as firm as before. Within the body there are structural adaptations which make it light. The air sacs opening from the lungs are good examples of such structures. They lie beween the large muscles, among the internal organs, and are even connected with cavities within the long bones. In order that flight may be swift and sure, the body must be rigid as well as light; there can be no wavering or the flyer will fall. To secure greater rigidity in the body, certain parts of the skeleton which consist of separate bones in other vertebrates are firmly united in birds. Each rib bears a projection (uncinate process) on one side which overlaps the next rib, thus making the body very firm during flight. Perhaps the most striking skeletal adaptation for flight is the great keel on the sternum, which gives attachment to the wing muscles.

The robin is not only well equipped to find and capture food, but is also able to profit by experience to a greater degree than a toad or a lizard. It soon learns to avoid undesirable objects, and usually hunts in favorable places at the most opportune times. After the food has been captured and swallowed, it is stored in the crop, ground among the pebbles which are present in the muscular gizzard, and then absorbed in the intestine. Digestion, absorption, assimilation, and excretion, are assisted by the digestive glands (liver, pancreas) and by certain ductless glands (pancreas, thyroid, thymus) which act "indirectly" by secreting substances into the blood.

The circulatory system of birds presents some points of special interest. At one time within the egg a robin has several pairs of aortic arches, but these degenerate or are diverted to various parts of the body as development proceeds, and an adult bird has only one great aortic arch, which curves to the right after leaving the heart and then runs backward as the dorsal aorta (Fig. 105). The heart in all birds has four chambers—the left auricle and ventricle collect and pump blood to the lungs for aeration; the right side receives the "pure" blood from the lungs and forces it through the body. Because of the active life a bird leads, metabolism is very rapid. The body temperature is even higher than that of mammals, and respiration is accordingly accentuated. A bird breathes through its lungs into air sacs beyond.

The excretory products of a robin pass into the cloaca from the kidneys and are eliminated through the anus with the fæces. They are chiefly in the form of uric acid, which is a solid and therefore well adapted to an aerial animal. A robin must be light and could not carry a great quantity of water, which would be necessary to dissolve urea.

Self-protection.—A robin's keen eyes and ears usually give adequate notice of approaching danger; any shadow which indicates a prowling hawk causes a speedy retreat

to some thicket; any unusual sound causes the sharp eyes to seek its source. Raptorial birds, weasels, snakes and other animals catch robins when they can, and are particularly likely to prey upon young individuals. In a general way the coloration of a robin protects it from such sharp-eyed enemies. The body is countershaded (dark above and light below) so that it is not conspicuous when illuminated from above, because the lighter parts are in the deepest shadow. The pigments in the feathers also blend well with the tree trunks and branches which robins usually frequent. When a robin is alarmed or threatened with danger it gives certain call notes which warn its fellows of the trouble, so that they may either look out for themselves or come to investigate the cause of the disturbance.

A robin is much better equipped than a lizard to meet the varying conditions of a terrestrial environment. Both have a dry skin which conserves the water within the body, but feathers are better than scales because they keep a layer of air next to the body which serves as an insulator against loss of moisture by evaporation or of heat by radiation. A bird is also more specialized than a lizard in having a constant body temperature which is maintained in spite of biting cold or extreme heat. Most robins migrate southward to pass the winter in a warm climate where food is abundant, but a few may linger in certain northern localities until spring. The migration of the robin covers a distance of approximately 3000 miles. In autumn the trip takes about eighty days, and in spring, seventy. The birds move northward as the mean daily temperature reaches 35°F.

Birds are subject to attack by various diseases. A robin may acquire bird malaria from the bites of mosquitoes, and certain bacteria may cause internal disorders. Trematodes and other worms live within the body; bird lice and other ectoparasites dwell among the feathers. Such diseases and parasites the robin avoids as far as possible by

scrupulous cleanliness. Frequent baths are taken, both in water and dust (the latter being distasteful to ectoparasites), the feathers are preened with the beak, and every precaution is taken to keep the body in good condition.

Race Preservation.—Though the female robin shoulders the chief responsibilities for the care of the eggs and the rearing of the young, the male is always at hand to encourage his mate, sound the alarm when danger threatens, or attack intruders. The pair select a suitable site, usually in an elm, maple, or apple because these trees have broad forks in the branches, and the female builds the nest. She first lays down a rough foundation of coarse stems, then brings load after load of grass and mud in her beak and builds a wall around the edge. Each time new material is added she scratches it into place with her feet, smooths and shapes it with her breast, and rounds off loose strands on the outside with her beak. The moulding, turning and smoothing movements are repeated hundreds of times. Finally a lining of soft grass or roots is placed in the completed cup and the nest is ready for the eggs. The male is constantly at hand and seems to furnish incentive to the female to carry on the work. If she goes for mud he follows a few feet behind, singing and showing great interest in all she does. If some other bird or small animal approaches the nesting place, the male attacks the intruder with great ferocity; if a danger threatens that cannot be combated he gives loud warning notes and stays near his mate to render assistance.

It requires from two to four days to complete a nest and the first egg is usually deposited from the fourth to the seventh day. After three or four eggs have been laid the female begins to incubate them, and for nearly two weeks leaves the nest only for short intervals to snatch a little food. The male is always near at hand, and helps in feeding the young birds after they hatch, but his mate still does the greater part of the work. The young have ravenous appetites, eating more than their own weight

every day. The attentive parents have to work from "early morn till dewy eve" to keep them satisfied. The nest is kept perfectly clean, all excrement or other dirt

(*Photos by A. R. Cahn.*)

FIG. 103.—"The wind blows east, the wind blows west,
The blue egg in the robin's nest
Will soon have beak and wings and breast,
And flutter and fly away."

being carried away by the parents. Even after the young have left the nest and are making short flights or hiding in the bushes, the parents watch over them.

The long period of care-free youth which robins enjoy enables them to reach a state of comparative independence under the protection of the parents. They do not encounter the force of the struggle for existence until they have attained somewhat of strength, vigor, and experience. The egg cell is stored with yolk, fertilized, and has passed through early segmentation stages before it is laid. As it passes down the oviduct more nourishment is added around the egg proper in the form of albumen, or "white," and the protective shell is then formed on the outside. While the young robin develops within the egg, it is constantly warmed and watched by the parents. After hatching, it is long the object of solicitous attention. Small wonder, then, that most robin eggs come to maturity.

A perch lays two thousand eggs, gives no attention to its young, and most of them are destroyed. A robin lays four eggs and usually hatches all of them. Why is one method better than the other? The net result in either case will perhaps be two or three new animals from each pair annually. The robin, however, has one advantage—the young pass through a long adolescent period during which they are cared for, and even trained to some extent by having opportunity to imitate their elders. The bird has more chance to acquire experience before being thrown on its own resources, and this gives opportunity for a higher grade of psychic development.

GENERAL REMARKS ON BIRDS

Birds all agree in having feathers, beaks, and characteristic feet, but all these structures show endless variations which are usually correlated with differences in habits and habitats. For example the feathers may be downy, or stiff and hair-like; the feet may be webbed, feathered, or naked; the beak may be hooked for tearing flesh, short and heavy for cracking seeds, or long and slender for probing in the mud. Each type of bird has the bodily parts highly

adapted for a particular mode of existence, which shows that birds are racially specialized.

Birds are unusual when compared with other vertebrates in having the ability to fly. Their exceptional agility has made it easy for them to capture food and escape from enemies, but they are not on the whole as versatile as mammals, partly because they are too specialized. They depend largely upon quickness and the acuteness of their sense organs. This has led to the extreme development of those parts of the nervous system which correlate accurate muscular movements and control reflexes; but the parts which have to do with thinking and scheming are comparatively simple. In the brain of a bird the cerebellum (which is concerned largely with the coördination of muscular activities) is very large and the cerebral lobes (where higher mental qualities reside) are small. In a mammal both regions are well developed. Birds, then, as a race, have sacrificed their power to develop great mental ability, probably because they became able to fly early in their evolution, and then were so specialized that they could not branch off on new evolutionary lines. The toes on the front limbs became degenerate to allow the formation of more effective organs for flight; the neck grew long and flexible to compensate for the resulting handicap in securing food; the teeth gave place to a horny beak. Specialization along such lines for a time made birds so successful that they became modified structurally to such an extent that they can never be racially youthful and have broad possibilities again. Birds as a race are in their old age.

As long as birds succeed with their present adaptations, however, they will dominate the air, and must be given credit for their exceptional flying ability. A fish-hawk can move as fast as an express train and may feed at will from the ocean or an inland lake, on the top of a mountain or in the bottom of a canyon. The best flyers among birds are the long-winged gulls, vultures, hawks, and man-

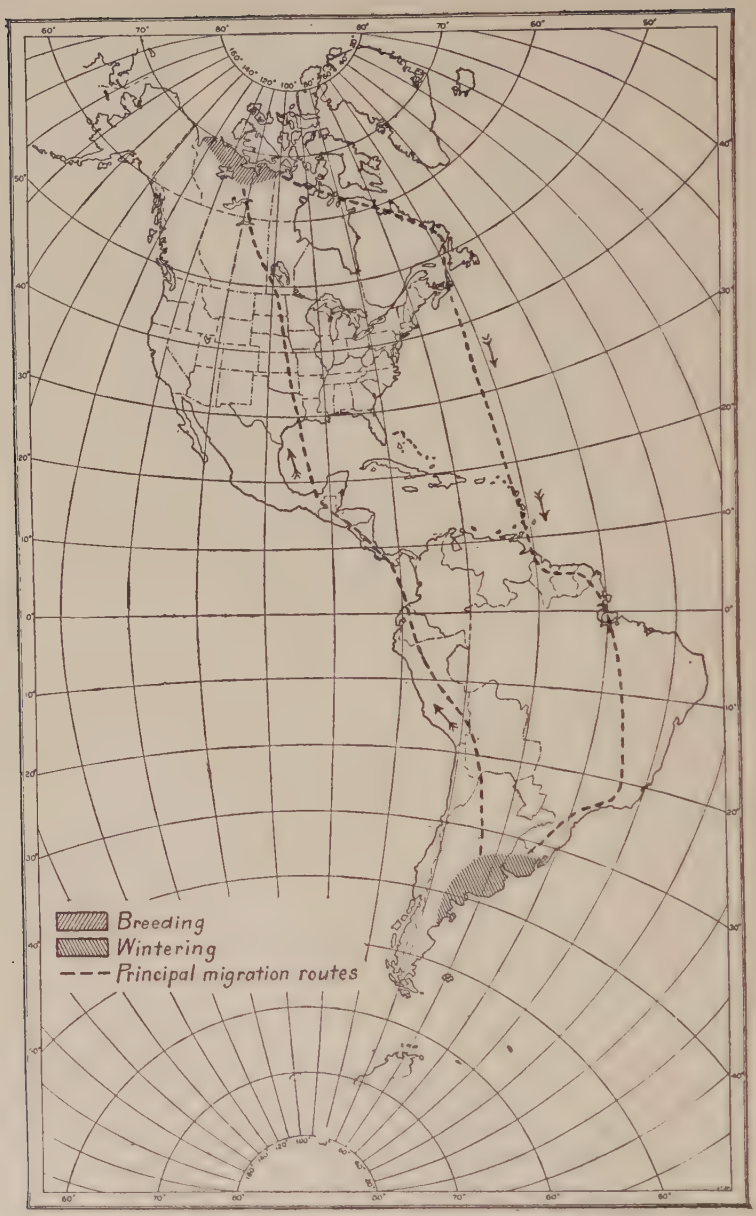


Fig. 104.—Distribution and migration of the Eskimo curlew. (*From Cooke; Yearbook, U. S. Department of Agriculture*, 1914.)

o'-war birds. Though most short-winged birds are poor flyers and tire easily, some sturdy forms like the ducks (which may attain a speed of a hundred miles per hour) are swift and effective on the wing.

The seasonal migration of birds has been a subject of much interest and speculation, but many of its aspects are still shrouded in mystery. Most small birds move about twenty-five miles a day on their journeys north and south. They usually travel high in air at night and rest during the day in appropriate localities. The Arctic tern annually travels "from pole to pole," thus living in perennial summer. The Eskimo curlew (Fig. 104) covers a great ellipse—south across 2500 miles of Atlantic ocean to its winter home and north through the center of North America to its breeding grounds within the Arctic Circle. On the other hand some birds, like the quail and the English sparrow, migrate little or not at all. Migratory birds usually breed in the coolest part of their range and spend the winter in warmer climates. The abundance of food and the presence of appropriate nesting sites are probably important factors in controlling such flights but they are not the sole causes of migration; in some species, in fact, appear to have little or no effect.

The songs of birds commonly serve for the attraction of mates, but various other characteristic sounds are useful for warning signals, calling the young, etc. The vocal apparatus of a bird is not in the larynx, as in mammals, but lies in the "syrinx" at the lower end of the trachea and is even sometimes imbedded in the sternum. It is a rather complicated apparatus, capable in many cases of producing a considerable range of sounds.

The colors of birds are for the most part protective. The body is countershaded (*i.e.*, is dark above and light below, so that the effects of light and shadow are eliminated,) and is therefore inconspicuous. Some birds, like the grouse, also have accurate pictures on the feathers of the backgrounds on which they are most apt to be seen. The fact

that a bird is bright colored is not necessarily to be taken as indicating that it is conspicuous in its usual habitat. Parrots, for example, are very difficult to see among the foliage of tropical trees. In some instances, however, striking colors may serve for attracting the opposite sex, or as recognition marks for other members of the same species.

The nesting habits of birds show various degrees of complexity and specialization in styles of architecture. A nighthawk builds no nest, but deposits the eggs on the bare ground, or sometimes even on a gravel roof. The burrowing owl of the western prairies digs a hole and strews manure on the bottom to keep the eggs off the ground. The bush-turkey of Australia builds great mounds of sticks and dead leaves in which the eggs are left to incubate from the heat generated by the decaying rubbish. Most passerine birds build nests like the robin, on the ground or among the branches of plants. The apex of avian architecture is reached in the beautiful basket nests of the orioles.

With a few exceptions birds incubate the eggs in nests or cavities which they construct. In general the length of the incubation period is proportional to the size of the egg, the smallest hatching most quickly. The emperor penguin carries its single egg between the hind legs, and male and female birds take turns holding it. Eggs laid in open nests are usually colored to match the surroundings, and this is particularly striking in those which are laid on the ground without a nest or with but a very crude one, as in the nighthawk or killdeer. Birds which nest in hollow trees or in holes in the ground usually lay white eggs.

Domesticated birds play a considerable part in modern civilization. The numerous varieties of the common hen probably all come originally from the jungle-fowl, *Gallus gallus*, of India. Domestic pigeons were derived from the blue-rock pigeon, *Columba livia*, a native of Europe and

Eastern Asia. Most of our tame geese originated from the graylag goose of northern Europe, and our ducks from the mallard. The peacock is a native of India, and the Guinea fowl came originally from West Africa. The turkey has been domesticated since the white man came to America, and, though rapidly becoming scarce, is still found in a wild state.

CHAPTER XXVI

SUBPHYLUM VERTEBRATA, CLASS MAMMALIA

A mammal is a warm-blooded vertebrate with hair and mammary glands. There are a few apparent exceptions to this definition. For example, some whales as adults are naked, in one instance having the hair reduced to two bristles on the upper lip; but before birth all have an abundant hairy covering. Mammary glands are found in all mammals. These are simply specialized skin glands which secrete milk to nourish the young. The ancestors of mammals were probably for the most part land animals, but in recent geological history many have become adapted to live in the water. Even the whales appear to have descended from quadrupedal forms which lived along the shores of ancient oceans.

All mammals have four-chambered hearts, like birds and crocodiles. They also have a single aortic arch carrying blood from the heart to the dorsal aorta, but in this case the one on the left side has persisted instead of that on the right as in birds. In passing from fishes to mammals the aortic arches, which in the simplest vertebrates carry blood to and from the gills, are progressively lost or diverted to other uses; the heart on the contrary becomes more and more complicated (Fig. 105). Fishes (A) usually have four pairs of functional arches which supply the gills, and possess a tubular heart; adult amphibians (B) have three pairs of aortic arches (only one of which connects with the dorsal aorta; the other two being diverted to the head, lungs and skin); the reptiles (C) have arches somewhat like amphibians, but in the crocodiles acquire a four-chambered heart; in the birds (D) and mammals (E) only one arch of a

single pair connects with the dorsal aorta and the heart is always four-chambered.

The teeth of mammals show great variations which in general are correlated with differences in feeding. The reptilian ancestors of the mammals possessed teeth and all existing mammals have them at some time. The curious duck-bill, certain whales, armadillos and the ant eaters have very rudimentary teeth, however, which do not break through the jaw and are resorbed before birth. Most mammals have two sets of teeth—a temporary or "milk" dentition and a permanent dentition. In some (guinea

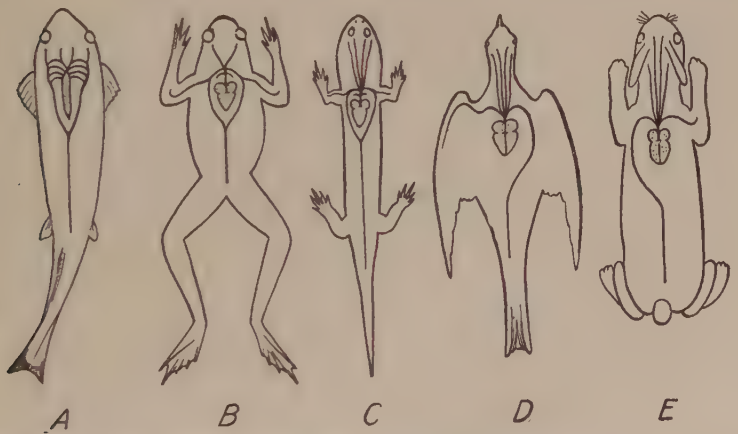


FIG. 105.—A comparison of the heart (dotted) and chief arteries in: A, fish; B, frog; C, lizard; D, bird; E, mammal.

pigs, bats) the former is lost before birth. The teeth may be all alike (homodont dentition), as in the dolphins, or show a differentiation into incisors, canines, premolars, and molars (heterodont dentition). The molars appear only in the permanent dentition. Very often animals which have a specialized heterodont dentition may lack certain types of teeth, and a diastema, or bare space, is left in the jaw. A squirrel, for example, has very large incisors but no canines and there is a gap in front of the premolars; a cow lacks incisors in the upper jaw and has no canines whatever.

In the mammals structures for reproduction and the nourishment of the young have attained far greater specialization than in any other group of vertebrates. The sexes are always separate, the egg is fertilized within the female and early stages of development take place within her body. The most primitive mammals lay soft-shelled eggs somewhat like those of birds, but the majority have the egg

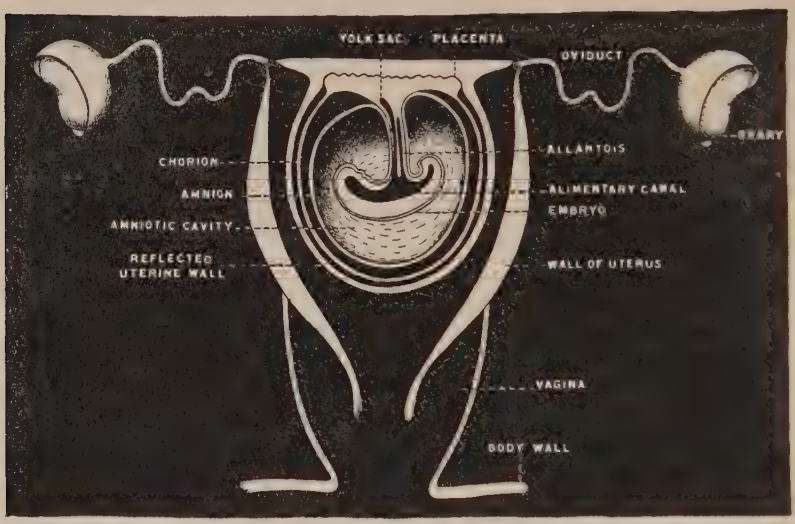


Fig. 106.—Section through body wall and uterus of a placentate mammal to show how the embryo is attached to the uterus. Drawn under the direction of Dr. E. A. Smith.

develop within the body and the young are nourished by the mother for some time—in many cases, both before and after birth. The young of the marsupials are at first very helpless. They are placed at birth in the marsupial pouch on the ventral side of the abdomen, where they receive protection and are nourished from the mammary glands. All mammals which do not lay eggs or place the young in a marsupial pouch show placentation of some sort. A placenta is a complicated structure which grows

out from the developing embryo and becomes fastened to the uterus of the mother in such a way that there is an exchange of nourishment between mother and offspring through the thin walls of the blood-vessels. All mammalian embryos, like those of reptiles and birds, are covered by a protective envelope, the amnion, before birth. This is filled with a watery fluid and its walls enter into the formation of the placenta.

Mammals are divided into large groups primarily on the basis of the degree of specialization in the reproductive and developmental processes. The groups are as follows:

Subclass I. Prototheria; egg-laying (oviparous) mammals.

Subclass II. Eutheria; viviparous mammals.

Division 1. Didelphia; mammals which carry the young in a marsupial pouch and nourish them before birth through a placenta which is usually very primitive.

Division 2. Monodelphia; mammals which nourish the young through a typical placenta, and never carry them in a pouch after birth.

Fossil records show that the Prototheria and Didelphia appeared on earth before the Monodelphia. There are also rudimentary structures on various representatives of the latter group which indicate that they came from marsupial ancestors. The fourteen orders of mammals which have living representatives will now be considered.

Order 1. **Monotremata.**—This order includes two primitive egg-laying mammals which live in Australia, New Guinea, and Tasmania. The skeleton and some other morphological features show affinities with birds and reptiles. The eggs hatch in a few hours and the young are at once placed in a hollow in the abdomen which is lined with mammary glands. There is no teat and the young lick the milk from the hairy surface of the skin.

The spiny ant eater, *Echidna aculeata*, has a long head and a mouth without teeth. Its tongue is very sticky and extensile, serving to capture ants. The duckbill, *Ornithorhynchus anatinus* (Fig. 107) is adapted to an aquatic life. It possesses webbed feet, thick fur, and a duck-like

beak with which it catches worms and insects under water. The male has poisonous spurs on the heels of his hind legs.

Order 2. **Marsupialia.**—The marsupials occur chiefly in the region of Australia, where they show considerable diversity. The dasyures and Tasmanian devil are carnivorous; the kangaroos (Fig. 107) and wallabys are vegetarians; the pouched moles burrow underground for insects; the phalangers live in trees and have prehensile tails. Yet, despite such variations in habits, with corresponding structural adaptations, all marsupials agree in possessing a pouch,

Fig. 107.—Duckbills, and kangaroo with young.

or marsupium, supported by a pair of marsupial bones which extend forward from the hips. The young are born in a very immature condition, transferred to the pouch, and attach themselves to a teat by means of a sucking mouth.

The opossums are confined to America, where they are the most important of the marsupial animals. Only one species, the Virginia opossum, *Didelphis virginiana*, is commonly found in the United States, chiefly in the south and middle west. This animal usually sleeps during the day and comes

out at night to hunt for insects, berries, nuts, small birds, mammals, eggs, etc. Two or three litters of four to six are produced annually. The young remain with the mother for a couple of months; at first in the pouch, then clinging to her back.

Order 3. **Edentata.**—As the name of this order indicates, the animals included have few or no teeth. The sloths, armadillos, and the American ant eaters are common representatives. The only species entering the United States is the nine-banded armadillo which occurs along the Mexican border. This interesting animal bears four young in each litter which are always of the same sex and result from the fragmentation of a single embryo. Such multiplication of the individuals from a single fertilized egg is known as polyembryony.

Order 4. **Insectivora.**—The insectivores are all small in size and live for the most part on or in the ground. The moles and shrews are common representatives in North America. The moles (Family *Talpidæ*) are stout, with powerful forefeet suited for digging, rudimentary eyes, and no external ears. The common mole, *Scalops aquaticus*, burrows just below the surface of the soil and, though it sometimes disfigures lawns, does considerable good by destroying insects. The shrews are tiny, shy, mouse-like creatures with pointed heads. Some species are among the smallest of mammals. Their food consists of insects, snails, worms, and other suitable objects.

Order 5. **Chiroptera.**—The bats belong here. The flying squirrels, and a few other hairy animals are able to sail short distances, but the bats are the only mammals which really fly. The digits on the fore limbs are spread out to support the thin wing membranes, the breast bone has a keel for the attachment of wing muscles, and there are other adaptations for aerial locomotion. Bats have remarkable ability to avoid obstacles while on the wing. An individual in which the eyes have been destroyed is able to fly about in a room crossed by a number of strings with-

out touching anything. Young bats cling to their mother and are carried about until able to take care of themselves.

Bats usually sleep during the day, suspended in some tree, cave, or belfry, and come out at night to seek food. The common bats in the United States are all insectivorous, but certain large, tropical species live on fruit and, in South America, the vampires bite sleeping animals and feed on their blood.

Order 6. **Carnivora.**—The carnivores may be terrestrial, arboreal or aquatic in their habits, but all have sharp teeth with prominent canines, and poorly developed clavicles. This order contains many animals of great interest to man—cats, dogs, fur-bearers, etc. It is usually subdivided into two suborders: (1) Fissipedia, including chiefly terrestrial carnivores; and (2) Pinnipedia, to which the seals, walruses, and sea-lions belong. There are a number of important families of carnivores in North America. The *Canidæ* walk on their toes (digitigrade) and have non-retractile claws. The dogs, foxes, wolves, and coyotes belong to this family. The raccoons (*Procyonidæ*) and bears (*Ursidæ*) walk on the entire foot (*i.e.*, are plantigrade). The martens (*Mustelidæ*) are widespread in North America; the forty-six species including the mink, weasel, marten, wolverine, skunk, badger, and otter. Many are greatly valued for their fur. The family *Felidæ* contains the carnivores with retractile claws—cat, puma, leopard, tiger, jaguar, etc. The aquatic carnivores (Pinnipedia) are greatly modified structurally for life in the water. The eared seals (*Otariidæ*), walruses (*Odobænidæ*), and the earless seals (*Phocidæ*) all have representatives on the shores of America.

Order 7. **Rodentia.**—Rodents possess strong incisor teeth fitted for gnawing and lack canines. They are usually of small or of moderate size, the jack-rabbit and beaver being among the largest known. In number of species this is the largest order of mammals, over fourteen hundred being included. Important representatives in North

America are the rabbits, hares (*Leporidæ*); squirrels, prairie-dogs, woodchucks, chipmunks, ground-squirrels, flying squirrels (*Sciuridæ*); beavers (*Castoridæ*); pocket-gophers (*Geomidæ*); rats, mice, voles, muskrats (*Muridæ*); and porcupines (*Cændidæ*). The beavers are unique among rodents in possessing a flat scaly tail which they use for swimming. The porcupine's quills are peculiar structures, which are to be looked upon as highly modified hairs. They must be touched to do injury and cannot be shot out as is sometimes believed. Rats have recently been the subject of special interest because of the discovery that their fleas commonly carry bubonic plague.

Order 8. **Pholidota.**—The scaly ant eaters, or pangolins, are peculiar mammals inhabiting Africa and parts of Asia. Their bodies are covered with flat scales and they roll themselves up into balls when molested, like armadillos.

Order 9. **Primates.**—This order includes the lemurs, monkeys, apes, and man. Its representatives are mostly found in the warmer parts of the earth and usually live in trees. They are well adapted to arboreal life, usually possessing thumbs and great toes opposable to the other digits so that the hands and feet are admirably fitted for grasping. Most primates are somewhat social in their habits and usually go about in small bands. One young is usually born at a time and it is attended with great care.

The lemurs (*Lemuridæ*) are dog-like arboreal animals, mostly confined to the island of Madagascar. They usually have a long non-prehensile tail and the toes bear both claws and flattened nails. The marmosets (*Halpalidæ*) are found in Central and South America. Their great toes bear flat nails but the others have claws; the tail and ears are long; the thumb is not opposable to the other digits; the brain is rather large; and the space between the nostrils wide. The South American monkeys (*Cebidæ*) have flat nails on all the digits and can oppose both the thumb and great toe; the tail is usually long and prehensile; and there

is a wide space between the nostrils. The old world monkeys (*Cercopithecidæ*) as a rule have long tails which are never prehensile; their buttocks are often covered with thick callosities which are usually bright-colored; the nostrils are close together. Many of these apes have cheek pouches for carrying food. They are found in Africa and Asia.

The anthropoid, or man-like apes (*Simiidæ*), spend most of their time in trees, and do not walk on the palm of the hand when on the ground like most monkeys, but stand more or less erect on the hind legs or walk in a stooping position resting partly on the backs of the hands. The tail is absent and the arms are longer than the legs. There are four genera of anthropoids which include the gibbons (*Hylobates*), orang-utan (*Pongo*), gorilla (*Gorilla*), and chimpanzee (*Anthropopithecus*). The gibbons are about three feet high and, though possessing very long arms, do not assist themselves with the hands when walking. They are found in Eastern Asia. The orang-utans live in Borneo and Sumatra. They use the knuckles of the hands in walking, and build platforms of sticks in trees. The gorilla is a native of West Africa, where it lives in trees and feeds chiefly on vegetation. It may reach a height of five and a half feet and weigh five hundred pounds. The chimpanzee lives in the same region but is smaller than the gorilla. It is more like man than any other living mammal. It is easily tamed, and has often been trained to perform various simple tasks.

The family *Hominidæ* includes only one species, *Homo sapiens*, or man. This is distinguished from other man-like apes by the erect walk, power of articulate speech, and marked ability to reason. There are three great races of men: (1) the Negroid, with dark skin, curly hair, flat nose, thick lips, prominent eyes, and large teeth; (2) the Mongolian, with black straight hair, yellowish skin, broad face with prominent cheek bones, a small nose, sunken, narrow eyes, and teeth of moderate size; and (3) the Caucasian,

having soft straight hair, vigorous beard, retreating cheek bones, narrow prominent nose, and small teeth.

Order 10. **Artiodactyla.**—This large order includes the hoofed animals with an even number of toes. There are many that are of economic importance, serving as fur or food for man and as his domestic animals. The pigs, peccaries, and hippopotami do not chew a cud, but ruminants (camel, deer, giraffe, prong-horn antelopes, and cattle) crop herbage hastily without masticating it enough for digestion and regurgitate it into the mouth later for thorough chewing. A typical ruminant has the stomach divided into four parts, the functions of which are correlated with the peculiar habits of feeding. The deer have solid horns which are shed annually but the cattle have horns with a vascular bony core and a hard outer sheath. The prong-horn antelope of Western North America is unique, having horns like cattle but shedding them annually. The descendants of the European *Bos taurus* are the commonest of the domestic cattle, though the water buffalo, yak, and others are important in certain districts.

Order 11. **Perissodactyla.**—The odd-toed hoofed animals include the horses (*Equidæ*), tapirs, and rhinoceroses. Though none of the Equidæ were found in America when Columbus discovered it, most of the past evolution of the family took place in the United States. The horses show extreme reduction of the pentadactyl limb; only the middle toe is functional and the terminal hoof represents the toenail. At the present time there are over sixty varieties of domesticated horses, all belonging to one species, *Equus caballus*. The asses, zebras, and quaggas still run wild in Africa and Asia, but several species have been tamed.

Order 12. **Proboscidia.**—The two living species of elephants inhabit Africa and India respectively. Both have five toes on all the feet, the characteristic elongated trunk with the nostrils opening at its tip, and a thick loose skin (whence the name, "pachyderm"). Elephants have no canine teeth; the tusks are elongated incisors. In rather

recent geological times certain fossil elephants, like the mastodon and mammoth, lived in the Northern Hemisphere.

Order 13. **Sirenia.**—The manatees and dugongs are large aquatic animals which live in shallow waters along the sea shore and in the mouths of rivers. These great animals live on vegetation and the bones are very heavy so that they may remain on the bottom without effort. Their limbs are modified to form flippers which, with the tail, serve for swimming.

Order 14. **Cetacea.**—There are two kinds of whales: (1) those with teeth (Odontoceti); and (2) those in which the teeth are never functionally developed, being present in the young but replaced by baleen or "whalebone" in the adult (Mystacoceti). Though whales are fish-like in general form and wholly aquatic in their habits, they are true mammals. The body before birth has a thick coating of hair, and the young are nourished with secretions from the mammary glands. A whale's nostrils open through the "blowhole" on the top of the head, and a great cloud of spray and vapor is spouted from this aperture when it comes to the surface to breathe. The toothed whales include the dolphins, porpoises, grampuses, killer whales, sperm whales, and narwals. The baleen whales are as a rule of large size, including the great rorquals, fin-whales, hump-backed, and right whales. "Whalebone" hangs from the roof of a whale's mouth in long plates which are frayed out at the free ends. In feeding, water is taken into the mouth and squirted out between the plates, thus straining out many small animals. The sulphur-bottom whale, *Balænoptera sulfureus*, is the largest living animal. It may attain a length of ninety-five feet and weigh nearly 300,000 pounds.

Probably the greatest interest which any man has in mammals relates to his own relationships to animals in general. The next two chapters will accordingly be devoted to man as an animal and his place in the animal kingdom.

CHAPTER XXVII

MAN, *Homo sapiens* Linnæus

'The proper study of mankind is man."—*Pope.*

Though zoologists were at first loath to admit their relationship to other monkey-like animals and for a time placed man in a distinct order of mammals, they have been forced by truth-seeking science to connect him closely with other primates. All types of men living at the present time are believed to belong to a single species, *Homo sapiens*, which is the only one in the family *Hominidæ*. The various races which are united in this species differ somewhat from each other but also have much in common. An individual from any one race is fertile in breeding with a representative from another, and there are no fundamental structural differences. Man must be looked upon as an animal belonging to the primates and showing closer similarities to his nearest relatives (chimpanzee, gorilla, gibbon, orang-utan) than they do to other monkeys.

Like all other animals, man's body is a machine which is controlled by such structures as levers, pulleys, muscles, sense organs, and nerves—all of which conform in their operation to the laws of chemistry and physics. His body is made up of cells which are like those of other animals; it originates by growth and cell-division from a single cell—the fertilized egg; and its cells show differentiation into tissues, corresponding to a similar division of labor in other vertebrates. There are many who believe that man differs from all other animals in possessing a soul, or spirit, which makes him unique. At the present time, science cannot state definitely that man, or any other animal, possesses or lacks a "soul," though there is often heated argument with eminent scientific men on both sides. But this

question does not properly come within the scope of this book and our attention will be directed to the more strictly zoological aspects of man's activities.

Self-maintenance.—Judging by the structure of the teeth and other parts concerned with nutrition, man is fitted to live on a diet consisting of fruits, herbs, and flesh. Savages often eat much of their food raw and devour things which have little appeal to civilized tastes. The American Indian revels in dog feasts; the primitive Australians esteem the luscious caterpillar as a great delicacy. Each race has certain food customs which are adhered to more or less strictly. The Italian loves his spaghetti; the Irishman relishes potatoes; the Australian prays to his gods that caterpillars may be abundant; the Hawaiian subsists largely on crabs and fish.

Though a man's body may be maintained for a considerable time by eating nothing but protein food, it thrives best on a varied diet including proteins, carbohydrates and fats.* Men forced to live without vegetables often have the scurvy or other similar diseases due to improper nutrition. Recently it has been discovered that certain foods contain very small quantities of substances (so-called vitamines, etc.) which play a very important rôle in nutrition, though they furnish very little actual building material or energy. For example, people living largely on polished rice may be attacked by the disease known as beri-beri; whereas those eating the same proportion of rice which has the outer brown covering are without such trouble. In the fat of butter there are minute quantities of another substance which stimulates growth. To have the greatest value, proteins, carbohydrates, and fats should occur in fairly definite proportions. The daily requirements for an average man as estimated by Atwater are as follows:

Protein	125 grammes (4.41 oz.)
Fats	125 grammes (4.41 oz.)
Carbohydrates	400 grammes (14.11 oz.)

* For definitions of these substances, see page 30.

The protein is used primarily for building body substance, and nitrogen is its most important chemical element. Carbohydrates and fats furnish energy to carry on the work necessary for the activity of the body, and their important element is carbon. If the daily ration is poor in protein, carbohydrates and fats cannot make up the deficiency; if it is lacking in carbonaceous substances, the proteins must be broken down in excess to release energy. In addition to organic foods, water and particular mineral salts are of course necessary.

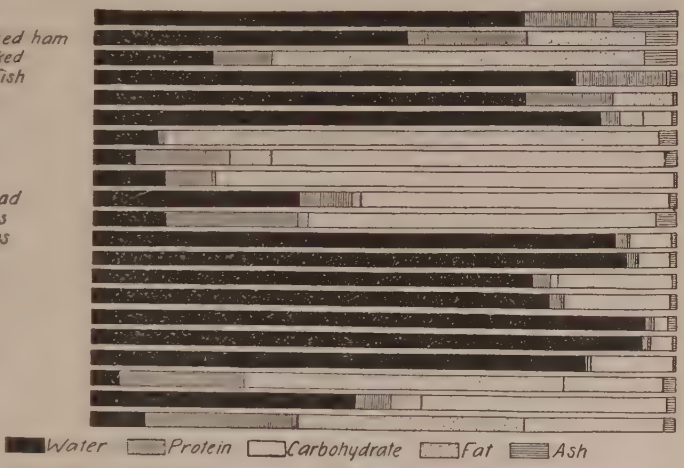


FIG. 108.—Constituents of common foods. (*From data in Sherman's Chemistry of Food and Nutrition.*)

Man is well-equipped to seek and capture food. A savage depends mostly upon his sight and hearing to discover suitable plants or animals, though the senses of touch, taste, and smell are often employed. The organs of smell are somewhat degenerate and far less effective than in many other mammals, such as the dog or deer. The position of the eyes compensates for this deficiency, however, by giving man the advantage of binocular vision which permits accurate judgment of distances to objects. The legs are well-suited for pursuing prey, and in some primitive races (Igorrotes) are used also for holding objects.

The hands are probably the best organs for seizing and holding that any animal possesses. They are equally effective for strangling a rabbit, holding a spear, or grasping a hoe, and the flat nails make it possible to pick up minute objects. The instinct for survival is strong in man and impels him to keep his body in training so that he may not fail in the chase. His superior mentality gives him a great advantage over other animals in securing food and he has been able to invent many means to insure a continuous supply.

Food, once in the hand, is placed in the mouth and goes the usual course—being chewed, swallowed, mixed, digested and absorbed. In the mouth food is mixed with saliva which contains the ferment ptyalin, capable of changing starch to sugar. As soon as the chewed food enters the stomach, gastric juice begins to pour out, but since the food remains in the upper part of the stomach for a time, ptyalin continues to act for about half an hour. Later it is neutralized by the free hydrochloric acid in the stomach. In addition to its digestive functions the acid acts as an antiseptic, killing bacteria and rendering certain other injurious substances innocuous. Gastric juice contains a protein-digesting ferment (pepsin) which liquefies the food by dissolving the nitrogenous substances. Most of the mixing and churning is done near the muscular outlet of the stomach and the liquefied food is gradually permitted to pass the sphincter* muscle which guards this opening. In the intestine muscular mixing movements continue and secretions from two great digestive glands (liver, pancreas) are mixed with the liquefied food. Pancreatic juice contains three powerful digestive ferments: (1) trypsin, for digesting proteins; (2) amylopsin, converting starches to sugars; and (3) steapsin, which breaks up and emulsifies fats. In the mouth the saliva has a slightly alkaline reaction. In the stomach the food becomes acid; is slightly alkaline or neutral after entering the intestine, but later

* A sphincter is a ring-like mass of muscle which surrounds an opening.

becomes acid again. The liquefiable nutriment is gradually extracted from the food and the residue of undigested material is finally eliminated through the anus. In a healthy man digestion is usually influenced by numerous bacteria which live in the alimentary canal. Some investigators assert that these unsuspected guests are absolutely indispensable for proper digestion.

The absorption of food is selective—not simply a soaking of liquids through the lining of the alimentary canal. If fresh blood is placed in the intestine it is not transferred unchanged to the adjacent blood-vessels but goes the usual long round of digestion, absorption, and assimilation. The proteins are mostly changed to amino acids and usually pass through the lining of the intestine into the blood-vessels; the fats are emulsified, broken up into fatty acids and glycerin and taken up by the lacteals;* the carbohydrates for the most part pass as monosaccharids in the blood to the liver, where they are stored as glycogen or transferred to the tissues to be burned for energy production.

Most of the activities concerned with digestion are under the control of the nervous system, but usually take place without the knowledge of the person who has eaten. Vomiting is a safeguard for rejecting poisonous or undesirable substances; headache may be an indication of an irritated stomach. Yet many of the digestive and assimilative processes are controlled by specific chemical substances, which may not even enter the alimentary canal. The pancreas not only manufactures a powerful digestive secretion which it pours into the intestine, but also acts as a ductless gland which is of great importance in connection with the utilization of sugar from the blood. When it is diseased the metabolism of carbohydrates is accordingly disturbed. Other ductless glands (thyroid, thymus, adrenals, gonads, etc.) all have more or less influence on

* Lacteals are branches of the lymphatic system which form a network about the digestive organs.

metabolic processes, though they take no direct part in the digestion of food.

The circulatory system of man is a highway for the transfer of food, waste products, gases, and the leucocytes which destroy undesirable materials. The food in the liquid portion of the blood is largely protein. Carbohydrates and fats are stored in convenient places within the body and enter the blood in small quantities as needed. The red corpuscles carry oxygen from the lungs to the tissues, and the blood returns to the lungs laden with carbon dioxide. The heart pulsates rhythmically for the entire life of a man, without rest, except what it snatches between beats. It forces blood through the arteries to all parts of the body, and is continually filled from the veins. Though the rhythm of pulsation is under the control of the nervous system, the tendency to beat is inherent in certain portions of heart muscle and movements may be induced or modified by the presence of certain salts in the blood or by other stimuli. Through the delicate walls of the capillaries, which connect the arteries and veins, food and oxygen are supplied to the tissues and waste materials enter the blood. Though the amount of blood passing through the heart may be the same at different times, the vasomotor nerves vary the diameter of the small vessels so that different parts of the body have more or less blood as their necessities demand.

The respiratory system is concerned primarily with the supplying of oxygen to the tissues and the elimination of carbon dioxide. Air is drawn into the lungs when the space in the thoracic cavity is increased by the contraction and descent of the diaphragm together with the raising of the ribs by the shortening of the muscles between them. Four hundred and forty liters (888 gallons) of blood pass through the lungs each day. To aerate this an adult man requires about 85,000 liters (3000 cubic feet) of air per hour. The atmosphere may contain 1 to 2 per cent. of carbon

dioxide and still be fit for breathing, but a greater amount is injurious.

The excretions formed as a result of metabolism are chiefly eliminated through the kidneys, lungs, and skin. The kidneys discharge the urea, formed as one of the end products when proteins break down. Though urea is excreted through the kidneys, it is formed for the most part in the liver and transferred in the blood. Water passes out through all three of the excretory channels; carbon dioxide is eliminated largely through the lungs, but some goes through the skin. All the excretory organs are controlled and coördinated by the nervous system. For example, in cool weather there is less water passing out through the skin and more through the kidneys.

The activities of the human body are more or less rhythmical. The day is usually a time of activity and the body is used up to some extent in doing work; night is a period of rest and losses are made good during sleep. Sleep is a curious phenomenon—sense organs which are at other times quick to receive stimuli become inactive and all extracorporal activities cease. There have been a number of theories to explain sleep and the three following may be mentioned: (1) Sleep may be caused by the using up of substances necessary for nervous activity; (2) it may be due to the accumulation of waste products which cause the enlargement of small blood-vessels throughout the body with a resulting scarcity of blood in the brain (though such changes do occur, they probably do not *cause* sleep); (3) sleep may be due to the contraction of nerve branches so that those of different cells are no longer in contact—thus the paths are broken along which nervous impulses travel when the body is awake. Whatever its cause, sleep is necessary for all warm-blooded animals, and the human machine is most efficient when periods of rest and activity alternate with reasonable regularity.

Self-protection.—The instinct for self-protection is as strong in man as in other animals and the body has many

natural adaptations for protection. Even its cells and fluids have properties which effectively shield them from dangers likely to be encountered. The skin usually keeps out undesirable materials. If it is broken, however, the clotting of the blood forms an effective plug which checks contamination from the outside. If bacteria or poisons do gain an entrance, they are eaten up by the leucocytes (which swarm through the blood channels to repel invaders), destroyed by antitoxins, or oxidized. Exposed parts of the body are especially protected by heavy growths of hair or callouses. Civilized man has devised clothing, houses, and other protective devices to assist his natural defences. Man is also one of the favored animals which have a constant body temperature, maintained by delicate adjustments and coördinations of metabolic activities, vasomotor nerves, and perspiratory glands. He is thus able to survive critical periods of climatic stress, when a cold-blooded animal would die. Man is also endowed with discriminating courage, reasonable fear, and a great degree of resourcefulness, so that he may fight, flee, or escape danger by using his wits.

Yet, despite all man's versatility in combating dangers, he is continually subject to minor disorders and is often killed outright by accident or disease. There are many chances for the occurrence of defects in the bodily machine. (1) A man may be born with some defect which cannot be corrected—hunchback is an example of such an affliction. Among the most pathetic of such cases are those in which the nervous system is defective. There is a malady known as Little's disease in which the body and mind may be perfect, but the nervous connections (pyramidal tracts) never grow down completely from the brain, as they should do about the time of birth. The bodily movements, therefore, are not coördinated because messages cannot be properly carried from the brain. A bright mind may thus wear itself out in a helpless but perfect body over which it has little or no control, and which ultimately dies from

lack of exercise. This disease is due to nothing but a lack of development and cannot be treated in any way. (2) A defect may be acquired through accident. Man has small power of regeneration when compared with many other vertebrates. A salamander can replace a lost leg but a man cannot grow a single joint of a finger. Specialization has gone so far that the tissues remaining can at best only close the wound. Accidents which maim or impair the nervous system are most serious; a sudden shock or strain may result in paralysis, insanity, or other permanent disorders. (3) The machine may be without serious structural defects but fail to operate properly. The digestive fluids may be too acid; excretions may not be properly eliminated and poison the tissues; the mind may not form sound deductions from observed phenomena. (4) Many occupations are conducive to specific diseases—the Indian leads an active life with much exposure and has his old age made unpleasant by rheumatism; the coal miner has his lungs impaired by dust and bad air, hence often acquires tuberculosis; the sedentary business man is dogged by insomnia and indigestion. (5) Clothing may be a source of diseases—improper shoes often cause permanently deformed feet; corsets may cause serious disturbances in the digestive, circulatory, or reproductive organs.

All the disorders mentioned up to this time are due to some defect in man's structural mechanism or in its operation, but there is another class of diseases (6) which are due to plant or animal parasites which actively invade the body. The chief avenues for the entrance for such undesirable organisms are through the natural openings in the skin, though some parasites enter in other ways (like the tetanus bacillus which gains access through cuts, and malaria which is injected hypodermically by mosquitoes). Such diseases as cholera, typhoid, trichinosis, and tapeworms, enter through the mouth with the food; diphtheria, infantile paralysis, tuberculosis, and some other diseases are usually spread through nasal discharges; the eggs of

certain parasitic worms pass out in the urine and hatch out larvæ which bore through the skin; some diseases (syphilis, gonorrhœa) are transmitted through the contact of mucous membranes with those of infected persons and are usually acquired by kissing or through sexual relations. Small wonder, then, that with so many opportunities to acquire diseases, measures are generally taken to combat them.

Modern medicine attacks disease along three general lines. (1) Preventive medicine educates the public. It spreads knowledge as to the nature of prevalent diseases and tries to lessen chances for their dissemination by improving sanitation, conditions of work, and diet. (2) Corrective measures attempt to help the body to work properly. Operative surgery adjusts structural defects; physic retains water in the undigested food and stimulates the flow of water into the intestine; strychnine in small quantities sometimes serves as a tonic to a fagged-out nervous system and allows it to recover its normal efficiency; a change in diet may alleviate some specific irritation; lenses may correct defective vision. (3) The killing or prevention of internal parasites is accomplished in various ways. Quinine is effective in poisoning malarial parasites in the blood corpuscles; thymol given judiciously will kill hookworms; the salts of mercury are injurious to the organisms causing syphilis. The human body has within itself certain reactions which are taken advantage of in preventing disease. Immunity to diseases may be natural or acquired. Most persons will not grow the virus of infantile paralysis in their bodies, thus showing a natural immunity. A person who has been sick with smallpox will not contract the disease again; he has acquired immunity because his body has formed antitoxins which prevent the growth of smallpox organisms. Modern medicine has made it possible to acquire immunity to certain diseases by contracting them in a mild form through vaccination. Under such circumstances the body during light attacks of disease develops

antitoxins which prevent the entrance of more serious infections.

Frequently the most difficult task of the physician is to tell what is the matter with his patient. The human body is such a complicated mechanism that symptoms may come by very circuitous routes and be difficult of diagnosis. Doctors are often blamed for not giving proper treatment when they have been obliged to choose from two or three possibilities. It is unfortunate that ability to diagnose correctly is usually difficult to acquire and comes only with wide knowledge and long experience, while the mere treatment of most diseases is comparatively easy.

Race Preservation.—Herter* says: "the sex instinct is the only human instinct that can be compared with the instinct of self-preservation in respect to the profundity of its influence on the conduct of man." The activities associated with mating, loving, and the rearing of offspring dominate the life of every normal adult individual. Though sex-determination perhaps depends only upon the presence or absence of an accessory chromosome in the sperm cell which fertilizes the egg and thus initiates a new human being, the two sexes show fundamental differences in their instincts.

A man is larger and stronger than a woman. His secondary sex characters (beard, deep voice, great strength, and more aggressive disposition) fit him to hunt, fight, or endure other privations necessary for the maintenance of a family. Woman, with her soft voice, mammary glands, and disposition to foster and cherish, is anchored to the central interest of family, forcing her to a relatively sedentary life. The structural differences between the sexes are associated with characteristic tastes and habits. "The essential differences between the mental life of woman and that of man apparently depends upon the fact that the cerebral organization represents and reflects the various aspects of the sexual functions, which irradiate as it were,

* "Biological Aspects of Human Problems," N. Y., 1911.

into the brain. The circumstances that the body of the mother nourishes both the embryo and the infant brings her into an organic relationship to family different to the casual relationship of the male."*

In the choosing of a mate the initiative is taken by the man. The primitive native of New Guinea adopts the simple expedient of killing the man who already possesses the woman he wants. In China and Turkey women are sold to men who may desire them. If men are to do the choosing, women must be attractive in order to be selected, and the gentler sex has developed charming qualities, both natural and artificial. The New Guinea woman dresses her hair by rolling strands in bright-colored clays in order

FIG. 109.—The races of men—Mongolian, Caucasian, Negroid.

that she may be more beautiful. Civilized women show the same instinct in their elaborate dresses, bright hats, ear rings, necklaces, and other ornaments. Forel, the eminent Swiss scientist, believed that many of the basic psychological processes of the human mind had their origin in the desire of the two sexes to appear well in each other's eyes.

A human being follows the same course of development as other metazoans. In a mature woman an egg cell leaves the ovary and starts down the oviduct about every four weeks. If fertilization does not occur within about two weeks, the egg cell passes out and is later succeeded by another. If a sperm cell unites with an egg cell, the resulting zygote adheres to the mucous lining of the uterus and development begins. After the usual cleavage stages (Fig. 64, page 152) a little streak (the primitive streak)

* "Biological Aspects of Human Problems," N. Y., 1911.

appears on one surface of the germ; folds then appear on either side of this streak and close over to form the nerve-tube. The germ layers (ectoderm, entoderm, mesoderm) are soon formed, the enteron and notochord take form, and at the end of the third week the heart of the embryo begins to pulsate (Fig. 115).

The human embryo has unusual opportunities for development. It is nourished for nine months in the uterus of its mother from her blood and rests in watery fluids surrounded by protective membranes (Fig. 106, page 288). The fully formed embryo, or fœtus, does not get blood directly from its mother. There is a transfer of nourishment and oxygen through thin membranes in the placenta. The blood in the fœtal circulation is very poor in oxygen and the fœtus is remarkably resistant to asphyxiation. This is a valuable adaptation for it prevents suffocation at the time of birth when the circulation from placenta to child is often cut off completely for some time. While within the mother the blood of the fœtus passes through the foramen ovale, an opening which makes a short cut between the two sides of the heart. There are other short routes so that most of the oxygen in the blood goes to the liver, heart, and head. At birth these channels close and there are fundamental changes in circulation and respiration. Sometimes some of them fail to close properly and a "blue baby" or other defective, which usually dies soon, results.

During the growth of the child the mammary glands of the mother have been changing and soon after birth they begin to secrete milk. This is a true glandular secretion and not merely "filtered blood." A child, then, like other mammals, has unusually advantageous conditions for development in that it may attain an age of nearly two years (after fertilization) without having any nourishment except that supplied by the mother. At about the time of birth important nervous connections are established by the growth of certain tracts of nerves through the brain and

spinal cord. A child at birth is rather helpless and does not correlate its movements well, but is nourished, cared for, and protected during this critical period. It also receives education, which even in the most savage races far exceeds that obtained by any other animal. It is taught to walk, talk, get food, care for itself, and to make implements. No wonder that man has been able to dominate the earth.

The most important structural changes which occur in a growing child after it ceases to be nourished by its mother are in the teeth and reproductive organs. A child usually acquires part of its first set of teeth before it is weaned (six to eighteen months); but children are rarely born with all their milk teeth, and others do not acquire any for more than a year. The second set of teeth usually appears between the ages of seven and twelve years, except the "wisdom" teeth which generally break through the gums before the twenty-fifth year but sometimes fail to emerge at all. The reproductive organs become functional in both sexes between thirteen and fifteen; the voice becomes deeper in the male and there are other accompanying changes. The ovaries cease their activities between the ages of forty and fifty, but the male reproductive organs may remain functional throughout life.

CHAPTER XXVIII

MAN (*Continued*)

THE MIND OF MAN

Man excels other animals in his combination of erect attitude, opposable thumb, unusual brain development, and powers of speech. The chief characteristic which has enabled him to outstrip all other competitors is his reasoning power. This of course has its seat in the nervous system and is dependent upon growth and cell-division for its full development. The nervous system of man, like that of all vertebrates, is formed by the turning in of a groove which is finally pinched off to form a tube along the dorsal side of the body (Fig. 91). As development proceeds (Fig. 104) the wall of the tube thickens and becomes folded in places; long fibers grow out from its nerve cells to all parts of the body and collect in bundles to form nerves. Sense organs develop, usually on or near the outside of the body, and become connected by nerve-cell fibers with the central tube. All the great nervous structure of an adult man has arisen by growth and cell-division from the zygote, formed when an egg cell and spermatozoon fused.

In its fully formed condition the nervous system consists of three classes of organs: (1) receptors, (2) effectors, and (3) adjustors. According to Herrick there are, instead of "five senses," about twenty-three kinds of receptor organs* in the human body which receive stimuli from outside or notify the central nervous system of conditions within.

* Separate receptors are stimulated by: touch and pressure, cold, heat, pain, chemicals, sounds, light, odors, muscle "tonus," tendon "tonus," hunger, thirst, nausea, suffocation, disturbances in circulation, sexual stimuli, distention of cavities (stomach, bladder, etc.), obscure abdominal changes, and tastable substances.

Many of these organs have great range of sensibility—the eye can perceive about two hundred pure tints, the average ear is able to discriminate some 11,000 different pitch qualities. Effectors are nerve endings for setting off organs which accomplish some particular work. They activate voluntary muscles, visceral muscles, or glands. The adjustors are groups of nerve cells and their branches, which lie for the most part within the thickened wall of the central nervous tube, or near it. They receive notice of conditions from the receptors, send out stimuli to appropriate effectors, and make necessary coördinations. A

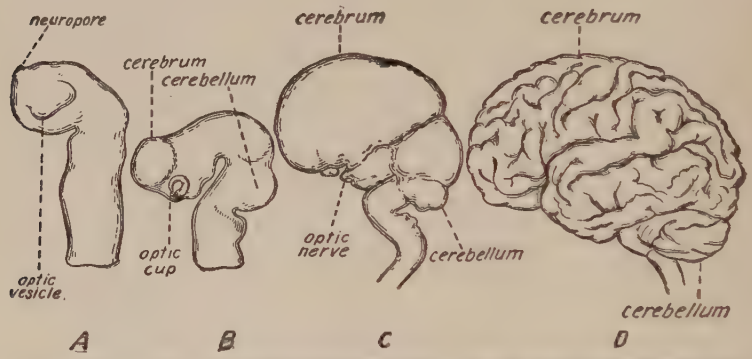


Fig. 110.—Development of the human brain. A, two weeks after fertilization; B, four weeks; C, during third month of fœtal life; D, adult brain. (*Largely after Herrick.*)

slight external stimulus may set off a great many effectors and thus cause a violent reaction, or a strong stimulus may be suppressed and cause no response—all such matters are arranged by the adjustors. For example, a pioneer may see a human form on the horizon—if it is an Indian with a gun, he will run or hide; if it is a member of his family, his nervous system will make no response through effectors to the image received through his eyes.

Man has many of his important sense organs localized at the anterior end of the body and it is but natural that the great adjustors should be close at hand in the thickenings of the wall of the neural tube which forms the brain. There

are two great swellings on the dorsal surface of the brain: the cerebrum, which is the seat of "voluntary" activity, consciousness, memory, and reason; and the cerebellum in which reside many of the centers for controlling the strength and steadiness of muscular activity. There are other adjustor groups of nerve cells in the brain, spinal cord, and among the internal organs. These for the most part control simple reflexes in organs near them.

The nervous activities of man are remarkable in two respects: (1) a vast number of practically unvarying and more or less automatic reflexes (which greatly exceeds that of other animals, except perhaps birds) is controlled by the nerve centers in certain regions of the brain outside the cerebrum and in the spinal cord; those concerned with the vital functions of the internal organs being dominated by certain parts of the brain (medulla, etc.), and those concerned with instinctive reactions of the skeletal muscles being largely controlled in the cord. (2) The higher mental faculties concerned with variable activities are developed as in no other animal. The enormous system of branching nerve cells in the outside layer of the cerebrum makes possible, not only the proper adjustment of the body to conditions as reported by effectors, but the storing of sensory memories upon which knowledge and the power of reasoning depend.

At birth a child has the main tracts in its nervous system formed, but is able during youth to strengthen or control its natural endowment by training. It may be naturally "bright" in solving mathematical problems, or "dull" in languages; awkward or graceful; docile or stubborn. Youth is the golden time for improvement, for there comes a day when the fiber tracts are no longer modifiable. As Herrick puts it, "the docile period is past, and though the man may continue to improve in the technic of his performance, he can no longer do creative work. Whether this process occurs at the age of twenty or eighty years, it is the beginning of senility. And, alas, this coagulation of

mental powers often takes place so early. Many a boy's brains are curdled and squeezed into traditional artificial moulds before he leaves the grades at school. We who seek to enter into the kingdom of knowledge and to continue to advance therein must not only become as little children, but we must learn to *continue so*."

ORIGIN OF MAN

According to Osborn* man probably arose during the Pliocene Period before the Glacial Epoch. At that time there were no men in Europe, but the remains of a very primitive ape-man (*Pithecanthropus erectus*) have been discovered in Java associated with the porcupine, rhinoceros, extinct species of elephants, and other animals which lived in the Pliocene Period. Java was at that time a part of the Asiatic continent and the primitive men were therefore free to migrate north and west, as they apparently did. The absence of hair in man indicates that he probably had his later evolution in a hot country. Osborn says: "It is possible that within the next decade one or more of the Tertiary ancestors of man may be discovered in northern India among the foot-hills known as Siwaliks. Such discoveries have been heralded, but none have thus far actually been made. Yet Asia will probably prove to be the center of the human race. We have now discovered in southern Asia primitive representatives or relatives of the four existing types of anthropoid apes, namely, the gibbon, the orang, the chimpanzee, and the gorilla, and since the extinct Indian apes are related to those of Africa and of Europe, it appears probable that southern Asia is near the center of the evolution of the higher primates and that we may look there for the ancestors not only of prehuman stages like the Trinil race but of the higher and truly human types."

Through recent scientific work the history of man in

* Osborn, H. F.: "Men of the Old Stone Age." 1915.

Europe is pretty well known. At different times various races came in from the southeast during the interglacial

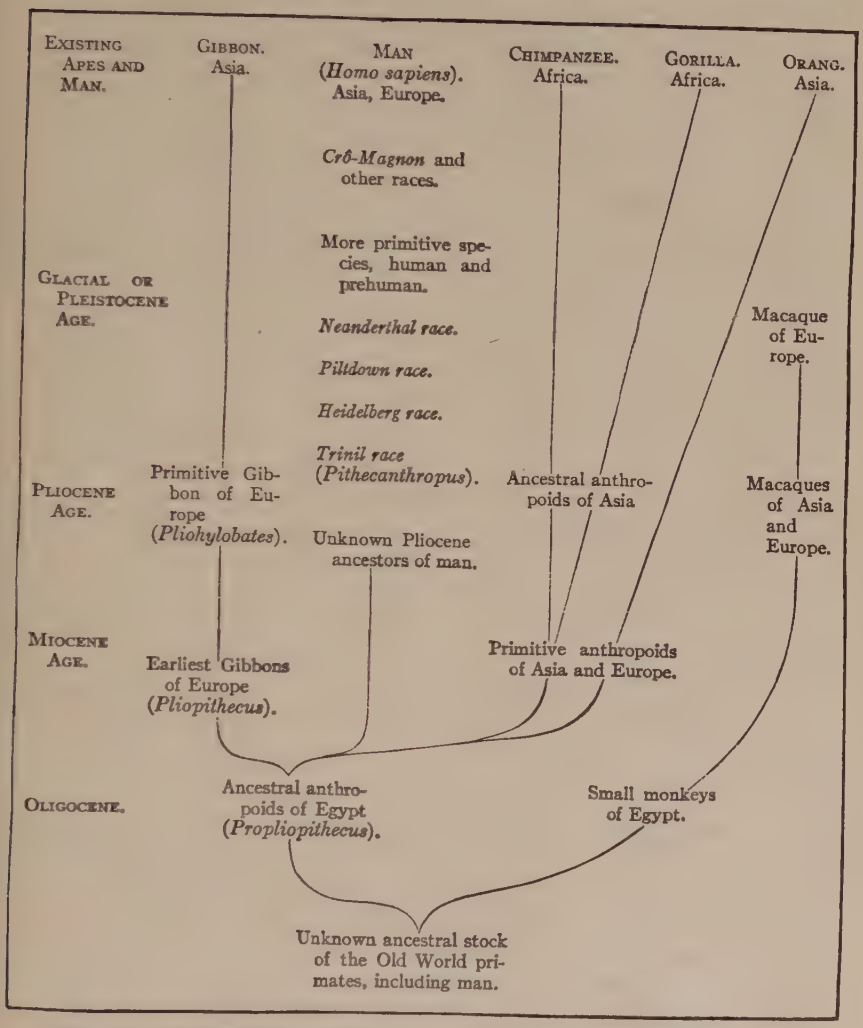


Fig. 111.—Ancestral tree of the anthropoid apes and of man. (*From Osborn's Men of the Old Stone Age.* By special permission of the publishers, Charles Scribner's Sons.)

periods of the Pleistocene. Europe was partly covered with ice four times and between each glaciation there was

a long warm period (Table I) when animals from southern countries invaded the land. In the deposits left during the first interglacial period eoliths, or unchipped stone fragments, occur which may have been formed by men, but

TABLE I.

Showing Conditions in Europe during the Development of Man
Adapted from Osborn's "Men of the Old Stone Age"

Time	Climate (COLD — WARM)	Animals	Implements	Human races
Postglacial 25,000 years		Deer, bison, horse, chamois, ibex	Iron 1000 BC Bronze 1000 yrs. Pottery Polished stone 5000 yrs.	Homo sapiens Brain capacity 2000 cc. Cro-magnon Race Brain capacity 1800 c.cm.
4 Glacial Period 25,000 years		Reindeer, arctic fox, muskox		
3. Interglacial Period 100,000 years		Bison, horse, hippopotamus, elephant, lion, rhinoceros, sabre-tooth tiger	Carving, painting Clipped flints 25,000 yrs. Rough flints 25,000 yrs	Neanderthal Race Brain capacity 1600 cc. Piltdown Race Brain capacity 1400 cc.
3 Glacial Period 25,000 years		Reindeer, wooly mammoth		
2. Interglacial Period 200,000 years		Hippopotamus, rhinoceros, elephant, stag, bison, horse		Heidelberg Race
2 Glacial Period 25,000 years		Reindeer, wooly mammoth		
1. Interglacial Period 75,000 years		Hippopotamus, elephant, rhinoceros.	(Eoliths?)	
1 Glacial Period 25,000 years		Muskox in England.		(Trinil race lived in Java) Brain capacity 900 c.cm.

most archæologists believe that they are not of human origin. In the long second interglacial period the Heidelberg race lived in central Europe. The men of this race

(*Homo heidelbergensis*) did not have a projecting chin like later races and were primitive in other features.

During the third interglacial period the flint workers entered Europe and attained a considerable degree of simple culture before the last glaciation again drove them south. These men at first frequented open camping sites in sheltered nooks along the hillsides, where the bones of animals slaughtered for food are found mingled with their primitive implements. Later when the climate became cooler they often sought the shelter of caves. Their implements were at first rough fragments of stone (eoliths), but later the stones were chipped to form various shapes (palæoliths). Little is known of the Piltdown race, except that it existed in eolithic times, but the Neanderthals (*Homo neanderthalensis*) left numerous remains in various parts of Europe and we have considerable knowledge of their customs. The bones of animals hunted for food are mixed with flints and with their own skeletons around the ancient hearths and give many clues to their habits of life. These men hunted the mammoth, rhinoceros, wild horse, bison, cattle, giant deer, and reindeer. Both flesh and pelts were utilized, and the marrow was sought by splitting all the larger bones. The chase was pursued with spears and darts fitted with flint points; also by means of throwing-stones. The Neanderthals may have used other means to secure large animals, for their small spears were probably not very effective against the mammoth or rhinoceros. At the end of their culture, bone came to be used somewhat for anvils and implements. The Neanderthals as a race possessed many structural peculiarities—the brows were heavy and overhanging; the forehead was low; nose, flat; upper lip, long; arms and shins, short. They became extinct during the fourth glacial period and were succeeded by a race which greatly excelled them in physique and intelligence.

The Cro-Magnon race, with others of less importance, entered Europe at the end of the fourth glacial period—

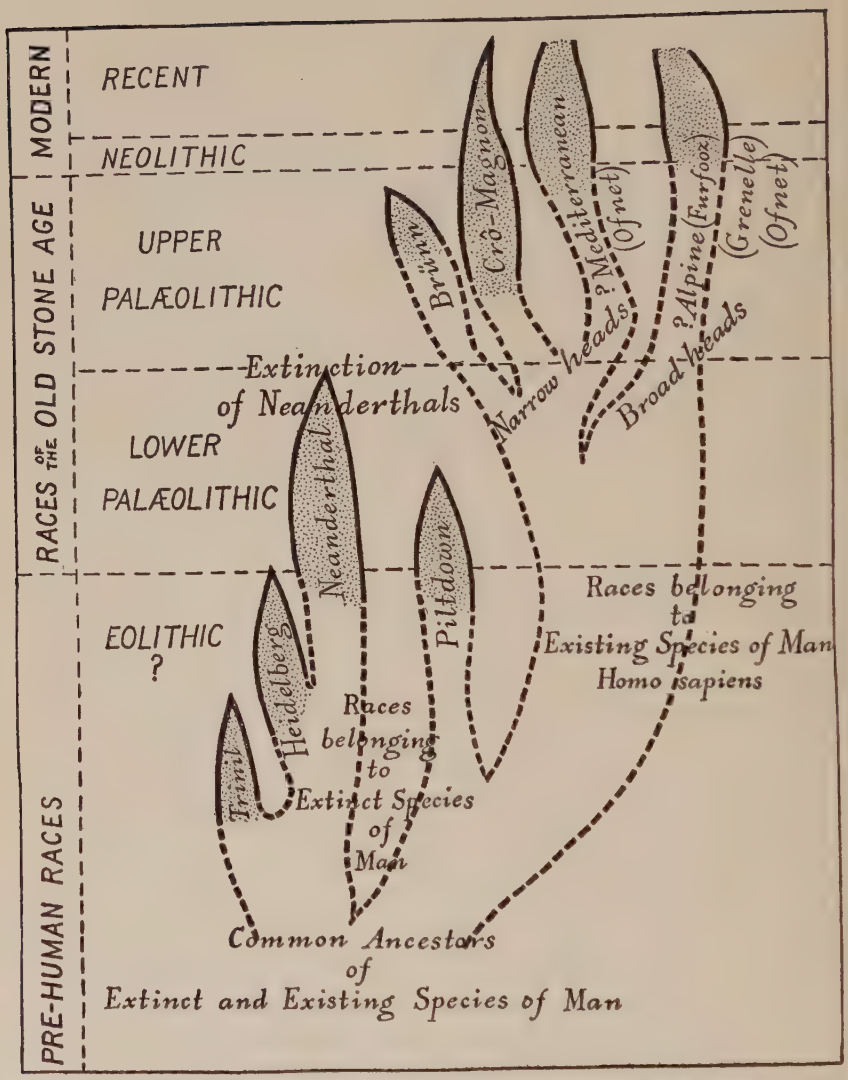


FIG. 112.—Tree showing the main theoretic lines of descent of the chief Pre-Neolithic races discovered in Western Europe. (*From Osborn's Men of the Old Stone Age.* By special permission of the publishers, Charles Scribner's Sons.)

about 25,000 years ago. These men are placed in the same species (*Homo sapiens*) as those of modern times; in fact, some are believed to have existed until the fifteenth century in the Canary Islands. They used bone needles, harpoons with recurved teeth, awls, hammers, borers, polishers, and perhaps bows and arrows. They also had considerable artistic ability, engraving on stone, bone, and ivory; sculpturing in stone, bone, and clay; painting on the walls of caverns; and making conventional ornamental figures. There was probably bartering at this time, for shells and other objects from the Mediterranean and Atlantic are found in Central Europe.

The Cro-Magnon race declined in later palæolithic times, though some groups persisted, and their descendants are believed to be now living in the region of Dorgodne and in some other places in France. The Old Stone Age (Palæolithic) lasted until 10,000 B.C.; then four new races invaded Europe, probably from the south and east. The new inhabitants lived more by fishing than hunting, and stag-horn harpoon points replace the older reindeer-horn spear tips in the deposits from this time. Art also declined and paintings were mostly confined to geometric figures on pebbles, which may have had some religious significance.

In the Neolithic (New Stone) Age polished stone implements succeeded chipped stone and agriculture began, for instruments for the preparation of the soil and the harvesting of crops appear in the deposits from this time. The most distinctive feature of the age, however, was the introduction of pottery. Art revived, and some of the drawings show the dog accompanying man, indicating that it had been domesticated. In the Old Stone Age the horse was commonly eaten, but that practice died out as it came under domestication. Cattle, sheep, goats, and pigs were also domesticated in the Neolithic age. Before the close of this period all the direct ancestors of the modern races of Europe had not only established themselves, but had begun to separate into colonies.

During the Stone Age, "the rudiments of all modern economic powers of man were developed: the guidance of the hand by the mind, manifested in his creative industry; his inventive faculty; the currency or spread of his inventions; the adaptations of means to ends in utensils, in weapons, and in clothing. The same is true of the æsthetic powers, of close observation, of the sense of form, of proportion, of symmetry, and the appreciation of beauty of animal form and the beauty of line, color, and form in modelling and sculpture. Finally, the schematic representation and notation of ideas so far as we can perceive was alphabetic rather than pictographic. The religious sense, the appreciation of some power or powers behind the great phenomena of nature, is evidenced in the reverence for the dead, in burials apparently related to the future existence of the dead, and especially in the mysteries of the art in the caverns."

HUMAN SOCIETY

All social relations depend upon mutual toleration and coöperation. Though those of man in part resemble the communities of social insects and vertebrates, which depend largely on primitive feeding and sheltering instincts, they have more of reasoning, self interest and altruistic love. The immediate ancestors of man were doubtless social in habits and probably possessed the power of communication by speech. The men of the Stone Age must have hunted together for the cave bear or mammoth and coöperated in the division of the spoils. They helped each other in averting dangers to themselves and their families; they dwelt together in the shelter of caves. Such association of different types of mind led to the exchange of ideas —men were stimulated to equal or excel their companions; improved methods originated by one were imitated by another. Members of the small society gained mental discipline and self control because they were obliged to sacrifice their own interests for those of the community.

Thus mind and thought have in part been products of the social medium.

The daily association of man with man made possible the many inventions and improvements in methods, tools, and other accompaniments of social life. There was progress from the use of rough stones, to the utilization and manufacture of chipped stones, polished stones, horn, bone, bronze, iron, steel and other metals. Some accidental burning of clay about a hearth perhaps led to the general use of pottery. The difficult and uncertain capturing of food through the chase gave place to the surer method of rearing domestic animals. The keeping of flocks was accompanied and in part superseded by agriculture. As hands became more skillful and minds more critical the manufacture of merely utilitarian implements was not satisfying—objects were made more symmetrical, embellished with engraving, and finally art became an end in itself. By conserving his resources and making his food supply sure man gained some leisure, and this led to the invention of games in order that he might share pleasant experiences and secure training in company with his fellows.

The collecting of groups of men for common interests and the enjoyment of social relations led to a "consciousness of kind." Each group drifted into certain methods and habits which became traditions for their children—thus clans with characteristic folk ways arose. Primitive races in all parts of the world frequently adopt specific marks to indicate their clan—nose rings, ear rings, painting the body, filing the teeth, flattening the head, etc. The fostering of clan spirit led to greater affection among members of a group and also brought about feelings of intolerance for other groups. It was natural, then, that there should be different dialects and customs. Certain laws were adopted by the clan and racial traditions developed so that group loyalty in time gave rise to patriotism. Group loyalty is strongest in primitive people; the most enlightened are tolerant of the idiosyncrasies of others.

The first human societies were families. Such primitive family groups still exist among certain tribes in the Philippine Islands and elsewhere. Among the American Indians each tribe consists of blood relations who trace their lineage to common ancestors. At the time white men came to America there were about 20,000 Iroquois living in the forests of New York. They were divided into separate "nations," each consisting of relatives, and to prevent close intermarriage there were laws which required young men to take wives from a different nation. Though these nations were affiliated there was no chief who ruled them all. The feudal chiefs of Bible times and during the Middle Ages were rich in cattle and sheep. In addition to their relatives, they required serfs and vassals to till the soil and tend flocks. These were voluntary retainers who sought the protection of some powerful chief, or captives taken in battle. From affiliations between such overgrown feudal families the nations of the earth arose.

In the development of nations climate has been an important factor. Where poor soil is coupled with arid conditions, the people are nomads and never form great societies. The struggle with nature for a bare living is too severe. But where there is good soil and abundant rainfall, agriculture and flocks flourish. Such resources enable men to acquire permanent homes, accumulate wealth, have leisure time for cultural pursuits, and to build up nations. On the other hand adverse climatic changes have made an end of great nations—the ruins of ancient Palmyra, which now lie in a desert, were built in the midst of agricultural plenty.

Through social intercourse man has made progress. There has been a gradual transition from the slaughter and capture of animals or the collecting of natural resources in the way of helpless shell fish, fruits, vegetables and seeds. The chase has been assisted by the invention of traps, arrows, spears, and firearms; experience has led to preparation for times of scarcity by storing reserves, and the inven-

tion of methods for curing food; the results of agriculture have been multiplied by cultivation and the selection of seeds. Modern economic relations have grown up chiefly through the accumulation and exchange of food products. Even the struggle between capital and labor is the result of primitive instincts to secure, to store up, and to improve the food. In modern civilization food and good living depend upon work or the possession of the results of somebody's labor. This has led man to adopt regular habits of life in order to be more effective and thus earn a better living.

CIVILIZATION

The Universal Dictionary says: "Civilization consists in what may broadly be called culture in a nation; and a nation may be considered as civilized when a large proportion of those belonging to it have their intellectual and moral faculties and all their higher nature in large measure developed and becoming increasingly so with the advance of years. Before this can take place a considerable amount of material prosperity must have been achieved, between which and the culture already described there are continual action and reaction. Regarding progression in material prosperity, certain stages tend to occur: (1) a barbarous one, in which one feeds on roots, fruits, and fishes, when these last can be caught without effort; (2) the state of a hunter; (3) that of the shepherd, in which, to avoid the uncertainty of the result in hunting, wild animals are domesticated; (4) the agricultural state; and (5) that of manufactures and commerce."

Civilization rests primarily on commerce. In primitive society there is little or no exchange of products; barter depends upon a market for surplus and cannot occur regularly in isolated communities where conditions of life are hard. The Esquimaux tribes, for example, are practically self-sustaining. Civilized nations have gone beyond the exchange of actual products and have money as a

medium of exchange. This condition is accompanied by more or less segregation into classes or castes; those with limited abilities or opportunities do the routine labor of the community, those with unusual endowments or good fortune accumulate stores of desirable assets. There is thus a continual struggle between those who sell labor and those who have wealth. The most pitiable "hangers-on" of modern civilization are those who make no contribution to society, but live parasitically on the fruits of the labor or the wealth of others. Commerce tends to eliminate tradition and the bigoted following of the folk ways of particular communities. As one nation associates with another and finds good workmanship, bright intellects, and shrewd minds, the contact is conducive to mutual respect and esteem.

The position of women in any nation is a fair standard of its civilization. In primitive societies men fight and hunt, women do all other necessary work. Work, therefore, is often looked down upon as something effeminate and unworthy of strong manhood. This attitude makes lazy men and overburdened women—a strong nation cannot result. Another evil that has often crept into half-civilized nations is slavery. In olden times slaves were one of the recognized rewards of conquerors and women were practically slaves to men. But slavery has decreased because it cannot be successful unless large quantities of new land are available for tillage. Furthermore, slaves are expensive and wasteful. They do not work to their limit of productiveness because they can receive no reward except "self-maintenance." No highly civilized nation countenances slavery today. In modern society, also, women are fast gaining legal, industrial, and intellectual equality with men. This does not mean that one sex will or should become like the other, but if civilization progresses each will have equal rights in society.

In the most cultured nations we can see many evidences of the primitive instincts for self-maintenance, self-

protection, and race preservation. Some dull souls are satisfied with mere self-maintenance and strive only for enough to eat and wear. Many business men are overcautious, stingy, and conservative, fearing for their own protection; others are greedy, unscrupulous, and aggressive in order to be sure to have enough. Our instincts for race preservation offer many problems—shall capital criminals be killed or encouraged to live better; shall hopeless idiots and insane persons be killed, sterilized, or allowed to live and breed other defectives? Class feeling not only displays itself today in patriotism, wars, and great struggles for national industrial supremacy, but is apparent in many harmless idiosyncrasies—such as cuffs on trousers, starched collars, the length of coat tails, and the trimming of hats.

In civilized life there must always be adjustment between individual rights and those of society. Economic conditions are keen, and the cities, which are the greatest industrial centers, show the greatest extremes—wealth, leisure, and culture contrasting with long hours, poverty, overcrowding, and ignorance. In civilization there must always be coöperation, sacrifice, and delegated authority. Often it seems that justice is obsolete, if individual cases are considered, but on the whole man's civilization grows higher and better. Certain aspects of modern life are highly desirable—the free interchange of ideas, the dependence of industrial progress on scientific method and discovery, the intellectual opportunities offered to all. But other sides of this life are not so desirable—the growing importance of labor-saving machines leads man more and more indoors where he falls prey to the diseases accompanying sedentary life; abnormal instincts for self-maintenance lead to the hoarding of vast fortunes which at times menace society; the wisdom of expending lives and resources in warfare is certainly questionable.

Religious beliefs of some sort have accompanied man's culture since its beginnings in the Stone Age. Many of the great reforms in society have been brought about by

changing religious ideals, and in this field Christianity has done more for improvement than any other religion. Most primitive religious beliefs have arisen from a desire for present help, retribution, or future life, and some races have been particularly "susceptible" to religion. The negroes, for example, in a savage state commonly believe in magic, charms, and the like; and when civilized are often religious enthusiasts. Semicivilized people generally believe in totems, charms, and transmigration. For example, the Alaskan Indian thinks that by making a clay image of his enemy and destroying it, he has injured the enemy; and that by wearing a charm simulating some animal he acquires certain of the qualities of that animal. What the outcome of the "higher criticism" of modern religion will be is uncertain, but one thing is sure—no religion which is largely form without high ideals and "service" can survive.

Probably the greatest burden that civilization and knowledge lays on man is—responsibility. If man rules the earth, he must do it with wisdom, kindness, and justice. He must conserve natural resources; protect helpless and ignorant nations. Through improvement in educational methods he must find some means to make the great stores of knowledge available as easily as possible. Education must more and more pass from mere training in observing and memorizing to training for the exercising of powers of generalization and ingenuity. Education has as its object the power to control self—to do more work and to do it better. Each generation must excel the one before and we do not know what the future of man will be. If he goes ahead as he has, it is possible that finally the universal exchange of ideas may bring about a ripe culture—which will mean universal coöperation, sacrifice, and toleration. If, however, a great disaster wipes out the human race, some other animal will have to struggle up through another long evolution and take its place. In either event the manifest duty of man is to do his best—to struggle continually to improve. Great nations must have great minds and spirits; these have always come from people who work.

CHAPTER XXIX

ANIMALS OF THE PAST

Chamberlin* maintains that the earth could not have originated from the gradual condensation of a gaseous nebula, as Laplace believed, but was probably ejected from the sun on account of the attraction exerted by a passing star. He believes that it probably solidified very soon and that it grew somewhat by the accumulation of smaller bodies (planetesmals) on its surface. "The juvenile shaping of the earth may be said to have begun as soon as the planetesmals began to plunge into the earth-knot of the nebula; and both knot and planetesmals began to gather into a dense body. The drawing of an atmosphere close about the young earth commenced almost simultaneously. The gathering of the primitive waters into the hollows of the earth-surface soon followed. These three concurrent activities were master-processes in the growth of the infantile earth; they were the geologic triumvirate. They wrought together toward the earth's final shaping into the lithosphere, the hydrosphere, and the atmosphere. The contact surfaces between earth, air and water are the sites of the most distinctive activities of the present day, and as far back as a good record goes these contact zones have been the seats of the most declared denudations and depositions. They have been almost the sole habitats of biological and psychological activity. From the naturalistic point of view these climatic developments embody three great steps: (1) an ascent in the complexity of physico-chemical combination until it attained the organic type; (2) an evolution of physiological processes and of organs subservient to these; and (3) the initiation and the varied development of

* "The Origin of the Earth," 1916.

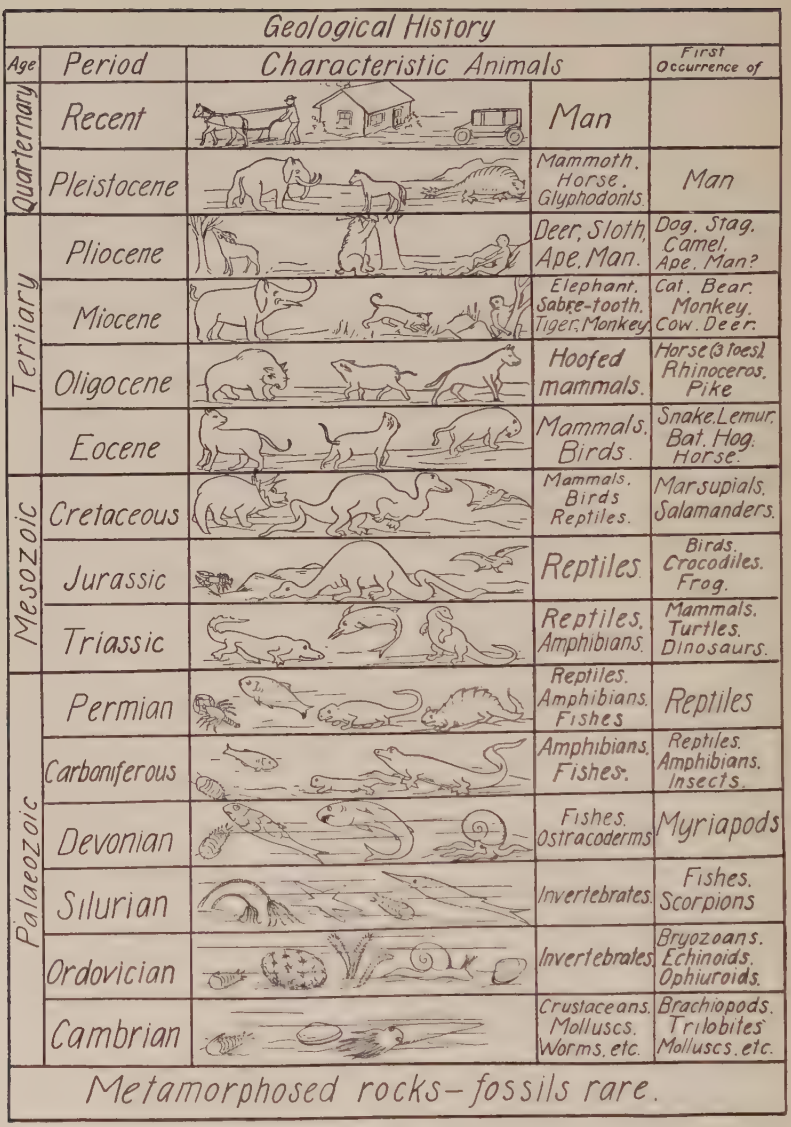

Geological History
Age
Period
Characteristic Animals
First Occurrence of
Quaternary
Recent
Man
Pleistocene
Mammoth. Horse. Glyphodonts.
Man
Tertiary
Pliocene
Deer, Sloth, Ape, Man.
Dog. Stag. Camel. Ape. Man?
Miocene
Elephant. Sabre-tooth. Tiger. Monkey.
Cat. Bear. Monkey. Cow. Deer.
Oligocene
Hoofed mammals.
Horse (3 toes) Rhinoceros. Pike
Eocene
Mammals. Birds.
Snake. Lemur. Bat. Hog. Horse.
Mesozoic
Cretaceous
Mammals. Birds Reptiles.
Marsupials. Salamanders.
Jurassic
Reptiles.
Birds. Crocodiles. Frog.
Triassic
Reptiles. Amphibians.
Mammals. Turtles. Dinosaurs.
Palaeozoic
Permian
Reptiles. Amphibians. Fishes
Reptiles
Carboniferous
Amphibians. Fishes.
Reptiles. Amphibians. Insects.
Devonian
Fishes. Ostracoderms
Myriapods
Silurian
Invertebrates.
Fishes. Scorpions
Ordovician
Invertebrates.
Bryozoans. Echinoids. Ophiuroids.
Cambrian
Crustaceans. Molluscs. Worms, etc.
Brachiopods. Trilobites Molluscs, etc.
Metamorphosed rocks—fossils rare.

FIG. 113.

psychological phenomena. These seem to have followed one another in ascensive order."

Though Chamberlin is willing, on the basis of observed phenomena and mathematical calculations, to postulate that life originated in the surface layers of the soil near water, there is no actual record of such origin. The life of the earliest geological periods has left no trace because the rocks have all been "metamorphosed," that is, changed by pressure, heat, or other influences so as to destroy all organic remains. Though Walcott has recently discovered a few fossils in Pre-cambrian rocks, the sedimentary deposits in the Cambrian are the first which contain abundant animal remains. In the Cambrian most of the chief groups of invertebrate animals appeared and many of them had already attained a high degree of specialization during the preceding formative ages. Fig. 113 gives a condensed summary of the chief events since Pre-cambrian times. The characteristic animals of the four great geological ages will now be considered.

PALÆOZOIC AGE

Cambrian Period.—The Cambrian fossils, so far as the animals are concerned, are all of marine origin, and it is doubtful if terrestrial animals existed. In the oceans there were protozoans, sponges, hydrozoans, jelly-fishes, corals, round-worms, annelids, echinoderms (cystoids, starfishes, sea cucumbers), brachiopods, clams, snails, cephalopods, crustaceans and arachnids. Doubtless other types of invertebrates were in existence but their remains have not yet been found. Some of the species which existed in Cambrian oceans did not survive even until the next period, and many whole groups became extinct during the Palæozoic Age. Trilobites of various sizes were common. The cephalopods usually had the body enclosed in a straight or slightly curved shell.

Ordovician Period.—In the rocks from this period appear the first remains of several classes of echinoderms (Blas-

toidea, Crinoidea, Ophiuroidea, Echinoidea), the Bryozoa, and certain molluscs. The trilobites attained their climax here and declined during succeeding periods. The cephalopods began to have coiled shells, which were less cumbersome than the straight types characteristic of the Cambrian. The graptolites, a peculiar group of cœlenterates, flourished in this time, but had a short racial existence for they were practically extinct at the end of the next period.

Silurian Period.—The most notable event recorded in Silurian rocks is the advent of fish-like animals. The ostracoderms had no paired fins or true jaws and differed from modern fishes in many other respects. Many of them had the anterior end of the body covered with heavy protective plates. There were also primitive sharks in the Silurian seas. In this period also the corals developed sufficient colonial life to begin to construct reefs; the brachiopods reached the height of their racial vigor; crinoids became abundant; the trilobites persisted in considerable numbers; the king-crabs had attained some specialization, and primitive sea-scorpions were in existence.

Devonian Period.—Fish-like animals increased greatly and many new types appeared. Though ostracoderms persisted and the appearance of new forms indicates that they attained considerable specialization, the whole group died out at the end of the period. Cyclostomes and sharks were present, and some of the latter attained a length of five feet. Several types of true fishes were in evidence—some were apparently ancestral to those living today and some have become extinct. The arthrodirans had the anterior part of the body covered with heavy exoskeletal plates, and were unique in possessing a neck joint so that they could nod the head. The trilobites were now declining and were replaced by crustaceans of more modern type. Most of the cephalopods possessed coiled shells, which in many species had a very complicated structure; clams became specialized to such an extent that forms much like

modern oysters and razor-clams were in existence. The presence of primitive myriapods indicates that the land had a well-established fauna at this time.

Carboniferous Period.—The rocks of the coal measures are of interest chiefly because they contain the remains of the first known animals with pentadactyl limbs. These were amphibians and some of them at least breathed air into the lungs when in the adult condition. They lived in fresh water and some may have been more or less terrestrial. All the Carboniferous amphibians are called stegocephalians because they had the head "roofed-over" with bony plates. Some were several feet in length and a number had teeth of very complicated structure (labyrinthodonts). Sharks were numerous and widespread at this time; true fishes were increasing in numbers.

Toward the end of the Carboniferous Period insects related to orthopterans, may-flies, and dragon-flies were living in the land vegetation, and there were other types which later became extinct. Various arachnids and a number of species of myriapods were also living on land. The brachiopods and the older classes of molluscs and echinoderms were declining in numbers. Only a single family of trilobites persisted to the end of this period. The abundant land vegetation was largely responsible for the coal deposits that are being mined at the present time.

Permian Period.—The number of species of amphibians increased somewhat during this period, but the most interesting feature is the rise of the reptiles, which came into existence in the preceding period and now invaded aquatic and terrestrial habitats. Reptiles soon showed specialization along a number of different lines. Some Anomodontia resembled mammals in many structural features, and in all probability the mammals later arose from this stock. Many of the old types of fishes were dying out, even that which probably gave origin to the amphibians declined, but their places were taken by species more like those of modern times. The trilobites, so characteristic of ancient

seas, became extinct and the ancestors of decapod crustaceans appeared. The land vegetation consisted largely of coniferous trees.

At the beginning of the Palæozoic Age, animals were represented only by invertebrates, but toward its close fish-like chordates, amphibians and reptiles arose, and gained prominent places. At the beginning also, most of the animals were marine, but, though the ocean continued to be abundantly populated, as life progressed in specialization there was an increasing invasion of fresh-water and land habitats. Many groups that were important in Cambrian times had dwindled (Brachiopoda) or become extinct (Trilobita) at the close of the Permian.

MESOZOIC AGE

Triassic Period.—During Triassic times the land was covered by great forests of coniferous trees, mixed with the older club mosses, ferns, and algæ. This luxuriant growth supported numerous insects and such modern types as the beetles had made their appearance. Some of the stegocephalians at this time were of great size, one species having a skull measuring more than a yard in length. Reptiles were more diverse and attained greater size than during the preceding period. The giant dinosaurs had appeared in various places; heavy-bodied plesiosaurs were beginning to frequent the shores of oceans; whale-like ichthiosaurs competed with fishes in marine habitats; chelonians frequented the swamps and rivers. Small mammals also appeared in the Triassic period, but did not take an important place among animals until later.

Jurassic Period.—Reptiles rose to the zenith of their development in this period and were distributed in all parts of the earth. Herbivorous and carnivorous dinosaurs (Fig. 101) dominated the land and frequented the borders of marshes; tortoises were numerous along rivers; the ocean

was frequented by large plesiosaurs and ichthiosaurs; the air served as a highway for the "flying lizards," or pterodactyls (Fig. 101). In later Jurassic times primitive birds (Fig. 102) appeared, and for a time shared the air with the flying reptiles. Mammals continued to be small in size, but had differentiated into types suggesting moles, opossums, and rodents. Fishes began to have more and more the structures associated with those of modern times: the endoskeleton became less cartilaginous and more bony; the heavy armour on the outside of the body decreased; the fins became more effective organs for swimming.

Cretaceous Period.—Dinosaurs and other great reptiles still flourished at the beginning of this period but before the close many whole groups had died out completely. The gigantic size of some of these animals is indicated by Shimer's estimates concerning Brontosaurus, an herbivorous dinosaur, which is believed to have weighed twenty tons and to have consumed about 4000 pounds of leaves and twigs per day. The birds of this time were not lizard like. Their tails were short and the wings did not generally possess free digits, but the jaws were armed with teeth. In some types there were signs of extreme specialization. Hesperornis, for example, had lost its power of flight and the wings were degenerate. The mammals were still small and for the most part not highly specialized.

During the Mesozoic Age the reptiles were the most important animals; though birds and mammals came into existence they did not play a prominent part in the life of the time. Toward the close of the age many orders of reptiles became extinct. Pterodactyls no longer sailed through the air; ichiosaurs and plesiosaurs were absent from the ocean; dinosaurs had disappeared forever. Among invertebrate animals there had also been many changes. In the ocean true shrimps, lobsters, and crabs had come into existence; the archaic cephalopods, so characteristic of ancient seas, were largely replaced by more

modern devil-fishes. On land insects were abundant and had probably come to take some part in the pollination of plants.

TERTIARY AGE

Eocene Period.—There were great changes of scene between the Cretaceous and Eocene. Many old types of reptiles and other animals were extinct; mammals now became the most important land animals. The ancestral stocks of rodents, elephants, bats, ruminants, whales, carnivores, edentates, and insectivores had already reached some degree of differentiation. There were also other primitive mammalian strains in existence which have since become extinct. Birds without teeth were present in considerable numbers and variety. The reptiles, amphibians, and fishes all had a more modern aspect. Such types as lizards, snakes, tailless amphibians, and herrings were prevalent. Among the invertebrates also there were hermit crabs, and other specialized modern types.

Oligocene Period.—There were now a number of types of hoofed animals in existence. Among the survivors of the strange herbivores of Eocene times, the rhinoceros-like titanotheres were perhaps the most remarkable, but they were all extinct before the beginning of the next period. The true rhinoceros stock was as yet hornless; the horses had increased to the size of foxes and their feet showed some degree of specialization toward the reduction of toes; pigs were small creatures with four usable toes on each foot; the ruminants were without horns, even the deer. Among the carnivores the sabre-tooth cats were perhaps the most striking though they had not yet attained their greatest size. These animals had the upper canines greatly elongated. Civet cats and carnivores related to modern weasels were in existence. Primate remains have also been found in the deposits from this period. The first pioneers of the Primates were primitive lemur-like animals. Among the birds there were divers like modern grebes, cormorants,

gulls, pelicans, rails, ducks, plovers, grouse, parrots and eagles. The insects were represented by such specialized forms as gall-flies, saw-flies, bees, stag beetles, and butterflies.

Miocene Period.—The landscape now had a more modern aspect. Among the plants were irises, pinks, poppies, violets, roses, plums, and pineapples. Various types of primitive monkeys were living in the trees. Porcupines, beavers, martens, skunks, bears, antlered deer, seals and other modern types lived with archaic forms like the hornless rhinoceri, and three-toed horses. In South America there were great ground sloths, some as much as twenty feet long, armadillos, and strange hoofed animals. A number of new types of birds appeared during Miocene times and other vertebrates were also changing. Snakes were now represented by venomous species.

Pliocene Period.—In this period many of the older mammalian types were still in existence. There were long-jawed elephants; horses in which the outside toes, though off the ground, were still quite large, sabre-tooth tigers, and other archaic creatures. But such old-fashioned animals were outnumbered by the modern types and old strains continued to die out. At the end of the period there were a number of kinds of true apes scrambling about in the trees; the horses were mostly "one-toed;" and there were many new animals, such as goats, giraffes, and even apes somewhat closely related to man.

The Tertiary Age is noteworthy for the increase of the warm-blooded animals, particularly the mammals. Though many lines of amphibians and reptiles underwent great specializations, these groups in general decreased, both in numbers and in variety. The birds and mammals, on the contrary, showed specialization along many and various lines, increased greatly in numbers, and filled many of the habitats occupied during the later Mesozoic times by their cold-blooded predecessors. At the close of the Pliocene,

though there were many relics from previous ages, the great majority of animals were much like those of today.

QUARTERNARY AGE

Pleistocene Period.—This was a time of great temperature changes, and the northern hemisphere was invaded four times by great masses of ice which came from the north. Climatic conditions caused great migrations among animals. Europe, for example was at times inhabited by reindeer, arctic foxes, musk-oxen, woolly rhinoceri, mammoths, and other animals characteristic of cool regions. When the ice receded, horses, elephants, sabre-tooth tigers, lions, hippopotami, and other animals came in. During the warm interglacial periods several races of men dwelt in Europe and attained a considerable degree of primitive culture. In South America giant sloths, peculiar camel-like creatures, and gigantic armadillos (Fig. 113) were still in existence.

Since the last great glaciation the northern hemisphere has enjoyed a fairly stable climate, vegetation has spread northward, and animals have increased in numbers. The most important feature of the Quaternary Age has been the rise of man and his domination of the earth.

PALÆONTOLOGICAL HISTORY OF ELEPHANT AND HORSE

The discussion of the geological periods necessarily has been very limited and noted only a few of the important events of palæontological history. In order to give a more concrete idea of how modern types of animals have developed from primitive ancestors, two of the best known series will be briefly described. These relate to the ancestors of the elephant and the horse.

The earliest elephant remains (Fig. 114, A) were discovered in Middle Eocene deposits in Egypt. The creatures from which modern types probably descended were small tapir-like animals, about three and a half feet high, which appear to have dwelt in swamps, living upon the succulent, semi-aquatic herbage of that time. Their front

teeth were rather degenerate, indicating a prehensile upper lip, and the second pair of incisors in each jaw were somewhat developed as tusks. In the Upper Eocene this

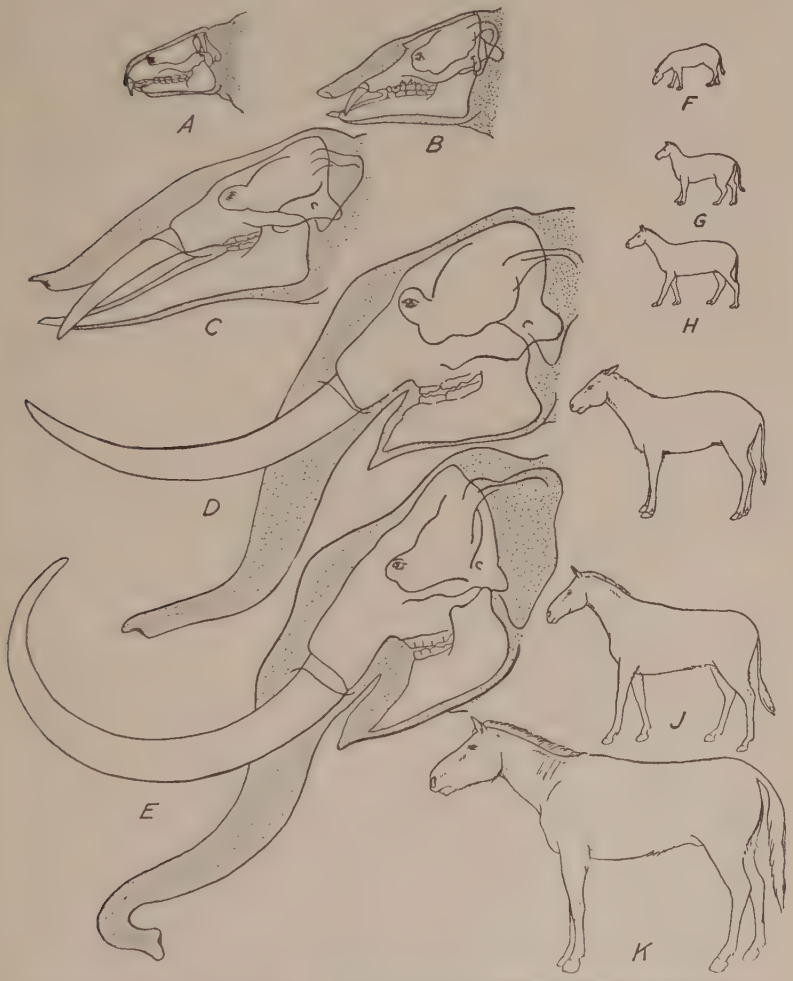


Fig. 114.—Showing fossil ancestors and living representatives of elephant and horse. (*After Lull.*)

primitive elephant (*Mœritherium*) was asssociated with a more specialized type (*Palœomastodon*, B) of somewhat larger size. This new elephant had a greatly elongated

lower jaw and the structure of its upper jaw indicates that it possessed a short extensile proboscis. No elephant bones are known from Oligocene deposits, but in the Miocene of France a great proboscidian, *Tetrabelodon*, has been discovered which is remarkable for the great elongation of the lower jaw and the shortness of the lower tusks (C). In Pliocene times several species of the genus *Dibelodon* lived in South America. These animals had well-developed tusks in the upper jaw but the short lower jaw was without incisors. The mastodon (D), which lived in North America during glacial times, had the lower jaw still further shortened. Modern elephants (E) apparently took their origin from a straight tusked type, *Stegodon*, which developed in the Indian region. The genera mentioned are only a few representatives of numerous types of fossil proboscidians. At one time there were elephants in Europe, Africa, Asia, North and South America. From what is known Lull is able to make the following generalizations concerning the racial history of the Proboscidia:

"The physical changes undergone by the race are also clearly shown, as the palæontological series is very complete. These changes may be thus summarized: Increase in size and in the development of pillar-like limbs to support the enormous weight. Increase in size and complexity of teeth and their consequent diminution in numbers and the development of the peculiar method of tooth succession. The loss of the canines and of all the incisor teeth except the second pair in the upper and lower jaws and the development of these as tusks. The gradual elongation of the symphysis or union of the lower jaws to strengthen and support the lower tusks while digging, culminating in *Tetrabelodon*. The apparently sudden shortening of this symphysis following the loss of the lower tusks and the compensating increase in size and the change in curvature in those of the upper jaw. The increase in bulk and height, together with the shortening of the neck necessitated by the increasing weight of the head with its great battery of

tusks, necessitated the development of a prehensile upper lip which gradually evolved into a proboscis for food gathering. The elongation of the lower jaw implies a similar elongation of this proboscis in order that the latter may reach beyond the tusks. The trunk did not, however, reach maximum utility until the shortening jaw, removing the support from beneath, left it pendant as in the living elephant. The change in the form of the skull developed *pari passu* with the growth of the tusks and trunk as it is merely a mechanical adaptation to give greater leverage in the wielding of these organs. It may readily be seen that these changes curiously interact upon one another; the result of the evolution of its parts being the development of a most marvelous whole."

Though elephants passed most of their evolutionary history in Africa, America can claim the distinction of having been the chief field for the evolution of horses. Lull says: "These horse-like animals, to which the name of *hyracotheres* has been given ranged throughout the entire Eocene period. They were of small size ranging upward from eleven to fourteen inches at the shoulder. The hand bore four digits, while in the foot but three out of the primal five remained. *Hyracotherium* itself, the oldest of its race, is known from a skull found in the London Clay, while both in England and America is found the widespread Dawn Horse, *Eohippus*. The scene of the evolutionary drama being shifted to our land, we find *Eohippus* (Fig. 114, F) succeeded by the somewhat larger *Orohippus*, the mountain horse (G), while *Epihippus* carries the race close to the close of Eocene time, a duration of at least two million years." During the Oligocene lived *Anchitherium* with three functional toes on each of its feet; the speedy *Mesohippus* (H) was eighteen inches in height at the withers; and its successor, *Miohippus* (I), stood twenty-four inches high. "The Miocene period was the millenium of mammals, and this was superlatively true of the horses." Though three-toed horses lived in the early part of this period, they were

later replaced by one-toed types, and in the Pliocene appeared the genus *Equus* (J, K) to which all living horses, asses, and zebras belong.

GENERAL REMARKS ON PALÆOZOOLOGY

The geological periods and the important features of palæozoology are shown in Fig. 113. There is no doubt that the great landmarks of this history have been correctly interpreted—strata of sedimentary deposits have been formed on the earth's crust and the deepest of these are the oldest. From studies of the characteristics of rocks and the animal remains in such deposits the following generalizations may be made:

1. *Conditions on the earth have varied.* There have been times of rapid change when whole groups of animals became extinct because they were unsuited to new conditions, and these have alternated with long periods of comparative stability when particular types of animal life multiplied and became specialized along various lines.

2. *The animals of the earliest times were predominantly marine* and in later ages the land and fresh water have had an increasing population. Structure is so correlated with habits of life, that, taken with the nature of the sediment in which fossils are found, it enables a palæontologist to picture the conditions in which an animal lived millions of years ago.

3. *The geographic distribution of animals today is correlated with their origin and distribution in the past.* A group of limited range is usually of rather recent origin, whereas one which is widely distributed is old. Zittel says, "An understanding of the physical conditions which have governed the perpetuation of recent plants and animals in their respective provinces would be utterly impossible without a knowledge of their distribution in former times."

4. *The simplest, or most primitive, animals came first.* This is equally applicable to the sequence in the develop-

ment of the different phyla and to specialization within particular groups—Protozoa must have preceded Metazoa; crustaceans existed before insects. Fishes, amphibians, reptiles, birds and mammals have arisen since Pre-cambrian times and the order of their appearance agrees roughly with their degree of specialization. What has been said of animals applies equally well to plants. There has been a succession of algæ, mosses, ferns, conifers, and finally the seed-plants of today.

There have been great changes; the types of animals living today are few compared with those which have passed away forever. The animal kindgom past and present may be compared to a cotton-wood tree which is being covered by a moving dune; the living twigs are but a small part of the portions now covered by the shifting sands of time or dune.

CHAPTER XXX

EVOLUTION AND HEREDITY

"It has been a Proteus from the first; changefulness is its most abiding quality; in short, the essence of the creature is its innate creativeness." THOMSON AND GEDDES.

In the past various theories have been held in regard to the origin and descent of animals. Some scholars have supported the idea of (1) special creation (*i.e.*, that all species of animals were originally created as they now are), but since Lamarck and Darwin there have been an increasing number of those who believe (2) that living types of animals did not originate as they are today but have been transformed while descending from remote ancestors. The evolution theory, then, supports the principle of "descent with modification" as opposed to that of special creation.

Among scientific men evolution is no longer on trial, but is accepted as a fact. Throughout this book such a point of view has been taken for granted and it may now be well to examine more critically the facts and theories on which present ideas of evolution rest. In this connection there should be no confusion between what is known and what is believed—that there has been an evolution scientists do not doubt, but there has been, and is, much difference of opinion as to *why* and *how* changes have taken place. After accepting the (1) *facts*, and evolutionist must still puzzle over the (2) means by which *new species* have come into being, and why there is (3) *adaptation* to the environmental conditions in which animals live.

EVIDENCES OF EVOLUTION

Palæontology and Geographic Distribution.—As was stated in the last chapter, the earliest stages of the earth's

fossil records are lacking, but as far back as they can be read, they clearly indicate that the simplest, or most primitive, animals appeared first. Though many primitive types often persisted for long ages, there has been in general a progressive change to new and often improved forms which better met changing conditions of environment. In spite of the imperfection of the fossil record, there are a number of indubitable cases where series of stages which follow each other in order are known (horse, elephant, etc.). Thomson and Geddes say, for example: "What seems clear is this, that in early Eocene times there lived small five-toed hoofed quadrupeds of generalized type—that the descendants of these were gradually specialized throughout long ages along similar but by and by divergent lines, that they lost toe after toe until only the third remained, that they gained longer necks, more complex teeth and larger brains. So from the short-legged splay-footed plodders of the Eocene marshes there were evolved light-footed horses running on tiptoe on the dry plains."

Modern animals for the most part fall readily into a small number of phyla, which are rather sharply set off from each other. Only a few types have come down from the past, but there are some fossils (Archæopteryx, Fig. 102) which fill in certain gaps and indicate what the evolutionary changes have been. We also have living a few "links," like Peripatus (Fig. 33) and the duckbill (Fig. 107) which suggest relationships that would have remained unsuspected in their absence. Palæontology tells a story which is fragmentary but may be interpreted only in the light of evolutionary theories, and the story has no events that seriously interfere with such an interpretation.

Groups of modern animals in many instances are known to have had their past evolution in localities where they are now abundant. Each continent has certain types that are characteristic, both as fossils and as animals now living. Furthermore, groups which are known to have originated in rather recent geological ages have limited ranges of

distribution when compared with those of ancient lineage. Such facts lead to the conclusion that specific types originated in certain parts of the earth (centers of origin) and slowly spread to other favorable localities. Furthermore, it is well known that particular animals which have been isolated (on islands, in valleys surrounded by high mountain ranges, etc.) develop into types which differ in certain characteristics from those that are free to wander. For example, Australia has long been separated from other continents and has been subjected to comparatively slight climatic changes; its animals are primitive and show few close affinities with those of other continents. The fauna of the Galapagos Islands, while consisting of recent types, is composed largely of unique and peculiar species.

Generalizing from the facts of palæontology and the geographic distribution of animals, it may be said that generalized types preceded and gave rise to those of specialized structure, that particular species arose in certain localities and gradually spread to others, that species isolated and thus prevented from mixing with others are usually peculiar and rather closely adapted to local conditions.

Ontogeny.—The "Law of Biogenesis" asserts that "ontogeny repeats phylogeny" (page 60), and in general the evidence for evolution from the development of individual animals conforms with the sequence shown by stratified fossil records. All vertebrates, for example, pass through a fish-like stage (Fig. 115); palæontology shows that fishes were the first vertebrates to appear on the earth. From such facts the older evolutionists reasoned that at one time there were only fish-like vertebrates, and that these later gave rise to other more specialized types. This view has now been modified somewhat and at the present time the same facts are generally interpreted as meaning that all vertebrates are related because they pass through similar stages in development. The "fish-like" stage in the development of a mammalian embryo has gill slits and

its limb buds are somewhat like fins, yet such facts do not necessarily mean that mammals were fishes at one stage in their racial development.

Though the ontogeny of a particular animal usually repeats the general sequence of descent, the record may be warped or distorted by events which did not occur in racial development, or it may fail to agree in other respects. There are cases of "larval adaptation" in which a develop-

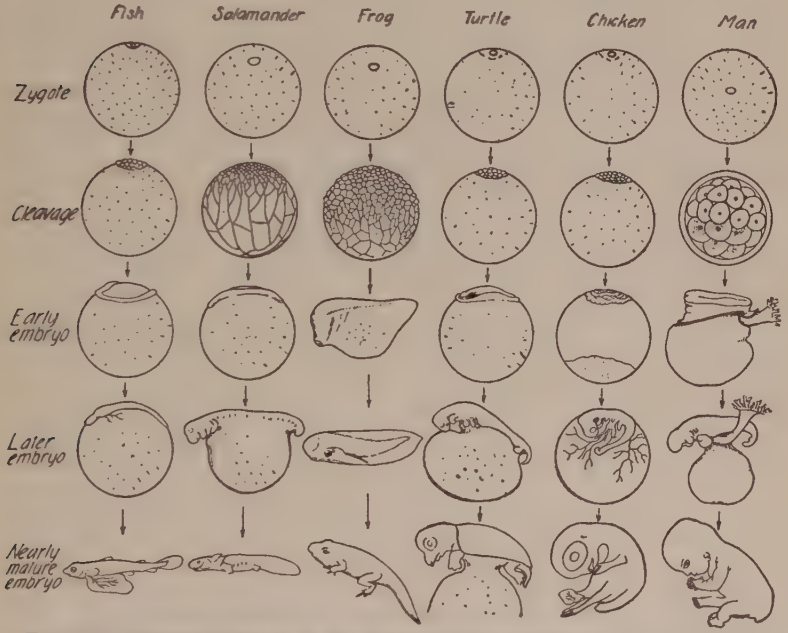


FIG. 115.—Showing stages in the development of vertebrates. The fish and salamander have functional gills in the last stage, but all other animals represented lose them in earlier stages.

ing animal possesses certain structures (placenta of mammals, Fig. 107; anal filament of young crayfish, Fig. 30) which could not have been present in mature free living ancestors when in a comparable stage of evolution. In other instances certain stages which probably existed in ancestral types have been dropped out. In such "acceleration in development" the record is not complete. It is

also probable that in the ontogeny of any animal there is wide discrepancy as regards the proportion of time between various embryological stages and comparable stages of the ancestors when in similar condition. Despite such imperfections in the ontogenic narrative, the development of animals, when taken with other evidence, gives valuable support to the theory of evolution.

To quote Thomson and Geddes: "It must be admitted that the recapitulation doctrine has been often stated in somewhat crude and exaggerated form, so that many saving clauses are necessary. The human embryo is never like a little fish or a little reptile; the resemblance is between embryonic stages. The recapitulation is general, not exact; there is often abbreviation and a masking of the old by the new. . . . It must also be frankly admitted that we are apt to get into a vicious circle in arguing about recapitulation. We infer the pedigree from the development, and then say that the development recapitulates the pedigree. . . . But when all is said, there remains good reason for keeping firm hold of this idea—that 'ontogeny, or the development of the individual, is a shortened recapitulation of phylogeny, or the evolution of the race.'"

Morphology and Classification.—If animals are classified on a structural basis without regard to evolutionary theories, they arrange themselves so that those which are genetically related come in the same group and a sequence is established which has evolutionary significance. Studies in classification and cataloguing first suggested evolution to Lamarck. At the present time systematic zoologists use all the evidences of evolution in attempting to establish more "natural" systems. Modern classification is founded on genetic relationship as judged by ontogeny, phylogeny, morphology, and physiology. A correct system of classification is also a genealogical tree.

Morphology, of itself, furnishes good evidence for evolution. The presence of useless vestigeal organs (man's appendix, whale's teeth) is hard to explain except as a

survival of structures which at one time in racial history were functional. The principle of "homology" has also been of value in supporting evolutionary theories. For example, all vertebrates have the same series of bones arranged in the same way in their limbs, but there is great variation in proportions. It is difficult to explain why such diverse organs as a frog's leg, a whale's flipper, a bird's wing, and a horse's foreleg should show homology, unless it is assumed that all vertebrates came from a common ancestral stock.

Physiology and Ecology.—There are many facts in physiology and in the relationships of animals that are readily interpreted by evolutionary theory. The functional activity of the nervous systems shows steady progress from the simpler to more complex animals. Starting in sponges with separate and independent effectors, simple reflexes are established through receptors and effector cells, there is combination and coordination of such reflexes by adjustors, and finally the more or less complete domination of primitive effectors and receptors by a central nervous mechanism.

It is hard to believe that such intricate relations as exist between parasite and host have been thus from the beginning of things. If, however, we assume that a liver fluke (Fig. 74) was first a free-living aquatic worm somewhat like a planarian (Fig. 73), that it gradually took up a parasitic life during succeeding generations and developed the ability to live and multiply during larval stages in the abundant nourishment provided by a snail's body, the case is much more understandable.

Experimental Evolution.—To any thoughtful person the proof of evolution would seem to lie in experiments and many attempts have been made to secure positive evidence in this way, but until the past few years there has been little that is satisfying. Recent investigators have contributed some valuable facts as to how animals vary and how particular hereditary characters are transmitted from

generation to generation. "In this case and throughout all consideration of 'evidences,' it must be remembered that the evolution idea cannot be logically demonstrated. It is not a simple induction from particulars, thoroughly as particulars support it. It is a way of looking at the becoming of things; and it is the only scientific modal interpretation that has been suggested. It is a formula that fits the facts, and all the facts it fits are its 'evidences.'" The most recent discoveries resulting from experimental methods will be discussed after the chief evolutionary theories have been stated.

THEORIES OF EVOLUTION

Though ancient Greek scholars (Aristotle, Lucretius) and others in later times (Buffon, St. Hilaire) had vague evolutionary ideas, the formulation of the two leading modern theories was due to Lamarck and Darwin.

Lamarck's Theory.—In the author's own words—"Changes in environment bring about changes in the habits of animals. Changes in their wants necessarily bring about changes in their habits, the new habits involve the use of new parts, or a different use of old parts, which results finally in the production of new organs and the modification of old ones." The central idea of this theory is the cumulative transmission of functional modifications—use or disuse makes a particular part of an animal increase or degenerate through successive generations. Lamarck further affirmed, "Nature preserves everything that she has caused the individual to acquire or lose by the influence of the circumstances to which the race has been for a long time exposed, and consequently by the predominant use of a certain organ (or in consequence of its continued disuse). She does this by a generation of new individuals which are produced with the newly acquired organs. This occurs, provided that the acquired changes were common to the two sexes, or to the individuals that produced the new forms."

There is no doubt that the use of particular parts makes them larger or more effective and that disuse makes them poorly developed and comparatively ineffective. The blacksmith's arm is strong; the banker's sensitive finger tips detect a spurious coin at once; the sedentary business man cannot run like a savage, and the provincial peasant cannot acquire broad knowledge. The chief weakness in Lamarck's theory lies in the fact that such "acquired characters" are not known to be transmitted in heredity. The banker's children are as easily deceived by bad money as was the banker before he began his training; the son of the blacksmith can have powerful arms only by constant exercise. In spite of this difficulty the theory, while not so successful as the next, still has many warm advocates.

Darwin's Theory.—Darwin's conception of evolution was that all animals and plants are subject to (1) small chance variations; thus certain individuals have a slight advantage over others in the (2) struggle for existence. This leads to (3) *natural selection* by a (4) survival of the fittest, and in time to the origin of new species. Darwin's theory is commonly known as "Natural Selection." Though it did not wholly discard Lamarck's ideas as to the transmission of acquired characters, selection was its important principle. It has been modified and supplemented somewhat since Darwin's time, but its chief features have stood criticism remarkably well. Briefly stated, the principal objections urged against natural selection are as follows: (1) that it does not explain how variations that are not useful from the beginning may be selected; (2) that variations in some cases at least are most apt to take place when the struggle for existence is not severe; (3) that it will not account for the perfection in detail which many structures have attained (*e.g.* the wings of insects that are remarkably like leaves, etc.); (4) that many apparently useless structures have developed along progressive lines; (5) that the range of variation is not modified by selection; (6) that chance variations cannot be the sole materials on which

selection must work to produce new types. These and others that might be cited, however, in no way invalidate the theory as a whole, and it is looked upon by the majority of scientific men as the best working hypothesis we have.

The following concrete illustration may serve to compare the differences between the two theories. From palæontological evidence it is known that the modern horse descended from ancestors which had several toes on each foot. According to the Lamarckian hypothesis the one-toed condition probably came about through use and disuse. In order to run more swiftly horses stood on the tips of the toes; the middle digit was used most and hence grew larger through successive generations; the toes on either side dwindled away with disuse. A Darwinian explanation of the same facts would suppose that ancestral horses varied among themselves; that those with larger middle toes were able to run faster and hence survived more often in the struggle for existence; that the middle toes were progressively larger and the side toes smaller because such conditions better fitted the environment. According to the first explanation the habit of using the middle toe and neglecting those on the side led to a one-toed condition; according to the second, the same end was attained by the selection by the environment of variations which made horses better fitted to survive in the struggle for existence.

VARIATION AND HEREDITY

Since the scientific world accepted the facts of evolution and had theories as to how the transformations came about, attention has naturally been directed to discovering how animals actually do vary and just how characteristics are transmitted from one generation to another. Variations have been carefully studied by statistical methods; thousands of individual animals have been measured and compared. Tests have also been made by breeding experiments to determine how particular characteristics are transmitted

from parent to offspring. Though all the problems have not been solved, the chief kinds of variations have been determined and some fundamental laws of heredity have been worked out.

Fluctuating Variations and Mutations.—Some characteristics vary according to the laws of chance on either side of an average condition. For example, the height of man is about five feet eight inches and it has been determined by a large number of measurements that the farther men depart in stature from this average, the fewer they are in numbers. There are many men whose height is five feet seven inches or five feet ten, but those that measure seven or five feet are rare. Such departures from the average of a species are called indeterminate, fluctuating, or "chance" variations. Sharply separated from these are those variations which show no gradations, but are clearly differentiated in each individual. The short-legged Ancon sheep appeared suddenly in stock which had previously possessed legs of normal type. When Ancons are bred with other sheep the offspring have long or short legs; there are no intermediate conditions. Such new variations which hold their own in heredity are commonly called mutations.

Orthogenesis.—Where variation proceeds in a particular direction through succeding generations it is said to be orthogenetic. Eimer was the first to point out that many variations do not follow the laws of chance but run in particular grooves. This discovery has been of great value in the understanding of certain points which were not readily explained by natural selection, such as cases of mimicry of one species by another and the very elaborate color patterns developed by some species. It makes the broad differences between groups of animals more easy to understand: *e.g.*, why the insects always have three pairs of legs; the spiders, four; and the vertebrates, two.

Somatic and Germinal Variations.—Weismann has made a distinction between variations which occur in the bodies of metazoans and those which influence their germ cells.

According to him the former are not inherited but the latter may lead to marked changes in succeeding generations. Weismann's Germ Plasm theory lays the whole responsibility for heredity on the germ cells; they are the "vehicle of inheritance" (Fig. 116). The body (soma) of each individual, though carrying the germ cells, is to be looked upon, from this point of view, only as a by-product of them. Each generation of germ cells produces enough soma (which includes all muscle, nerve, gland—even the mind and consciousness) to enable it to survive in the struggle for existence. But the germ cells control every detail of the body, and must be modified before there can be hereditary changes in the species as a whole. Nothing in the

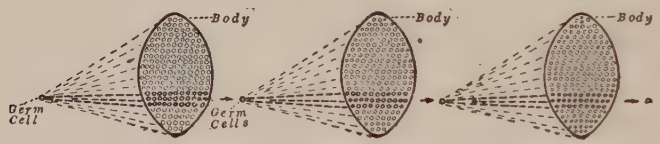


FIG. 116.—Diagram illustrating germinal continuity. Through a series of divisions a germ-cell gives rise to a body, or soma, and to new germ cells. The latter, not the body, give rise to the next generation. (*From Guyer's Being Well-Born*, Copyright, 1916. By special permission of the publishers, The Bobbs-Merrill Company.)

body can be inherited. All somatic qualities are caused by some modification of the germ cells, which reproduce all the "hereditary" qualities by which particular species are recognized in each generation. The soma dies at the end of each generation but there is no break in "continuity of the germ plasm."

Blending Inheritance.—Animals produced from a zygote formed by the union of two germ cells partake equally from each parent in many of their characteristics. A large rabbit, for example, when bred with a small one usually produces offspring of intermediate size. In many such cases of supposed blending, however, the succeeding generations do not retain the intermediate or blending condition but are separable into several groups. The increasing number of such "exceptions" has led some investigators to

believe that there is no such thing as the perfect blending of hereditary characters.

Mendel's Law.—There are many qualities which do not "blend" but are inherited as "unit characters"—that is, they are present or absent, or show one of two alternative conditions without intermediates. Such cases follow Mendel's Law, which supposes (1) unit characters which are (2) usually dominant or recessive and which are (3) inherited according to the laws of chance. Dominant and recessive characters may be present in a single individual but in such instances the former usually masks the latter

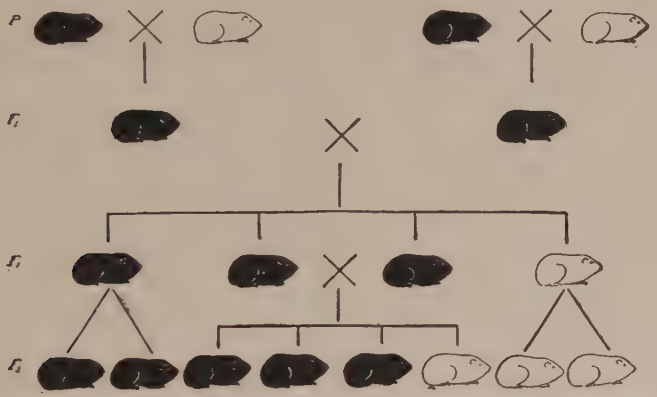


FIG. 117.—Diagram showing the scheme of inheritance in guinea pigs when black and albino forms are crossed. (*From Guyer's Being Well-Born*, Copyright, 1916. By special permission of the Publishers, The Bobbs-Merrill Co.)

so that only the dominant character is shown. In other cases the unit characters may produce an apparent "blend" in the first hybrid generation but later separate out and occur in later generations as they were in the original parents. Guinea pigs, for example, may possess a colored coat or be albinos with white hair and pink eyes. The pigmented condition is dominant to the albino. Therefore, if a black guinea pig (Fig. 117) is crossed with an albino the offspring in the first generation will all be black. These individuals are hybrids which possess both black and albino qualities, but show only the former because it is dominant.

In the next generation (F_2) however, the characters separate out according to the laws of chance and three different classes of individuals are produced in the following ratios:

1 BLACK: 2 BLACK (ALBINO): 1 ALBINO

The first and third classes will "breed true." If an individual from either of these is bred with another like itself, nothing but black or albino offspring will result. But the "black (albino)" hybrids if bred together (F_2, F_3) will always separate out into three characteristic classes—1 pure black; 2 black (albino); 1 pure albino.

Many pairs of dominant and recessive characters are known. Among these the following may be mentioned: brown and blue eyes in man; beardlessness and beard in wheat; rough coat and smooth coat in guinea pigs; normal condition and peculiar waltzing condition in Japanese waltzing mice. In each of the instances just mentioned the dominant precedes the recessive condition. There are other pairs of characters in which one does not dominate the other, but there is always segregation of the characters in the germ cells and chance for recombination after fertilization. It is the *segregation*, or separating out of unit characters, therefore, which is the important thing in Mendelian inheritance.

Bearers of Heredity.—In heredity particular qualities are not passed from parent to offspring but something is transmitted which determines what the character of the offspring shall be. A guinea-pig, for example, develops from a fertilized egg and is nourished by its mother during development. There is no white or black hair in the egg and there is nothing in the nourishment supplied by the mother that makes one or the other develop. Nevertheless there is something in the egg that makes black or white hair develop from the material supplied to the growing embryo. Evolutionists have given up the old idea that the fertilized egg contained a miniature but complete animal which simply enlarged its parts during development. There is not only

transformation of food material, but changes in structures as well. This has led scientific men to search for determiners of one kind or another. Darwin believed that there were particles (gemmules), of as many varieties as there are categories of cells in an organism, which migrated to all the cells during development and determined their specific type. There were serious objections to such a view, but other evolutionists have postulated somewhat similar determiners (micellæ, pangens, etc.). There is no definite evidence, however, in favor of any such arrangement.

The only positive evidence that indicates bearers of hereditary qualities points chiefly to the chromosomes. The fact that the chromosomes are divided with such care during mitosis indicates that their accurate separation is important. Biologists have long believed that this was an indication that they were the carriers of hereditary characteristics, and during the past few years Professor Morgan believes that he has secured evidence by breeding fruit flies (*Drosophila ampelophila*) which enables him to assign particular characteristics to each of the chromosomes known to be present in the germ cells. One chromosome, for example, apparently carries the factors for bent wings and eyelessness; another, those for banded body, dwarfing, white color of head, and at least twenty others; the two remaining chromosomes are believed to carry twenty-eight and forty-seven factors respectively. If chromosomes are the sole bearers of hereditary qualities, those of the fruit fly doubtless carry many more than have as yet been assigned to them. But Professor Morgan speaks with enough assurance concerning the behavior of those he has tested by experiment to be able to assign characters to particular positions on the chromosomes.

CONCLUDING REMARKS ON EVOLUTION

Morgan* says: "Today the belief that evolution takes place by means of natural processes is generally accepted.

* "A Critique of the Theory of Evolution," 1916.

It does not seem probable that we shall ever again have to renew the old contest between evolution and special creation.

"But this is not enough. We can never remain satisfied with a negative conclusion of this kind. We must find out what natural causes bring about variations in animals and plants; we must also find out what kinds of variation are inherited, and how they are inherited. If the circumstantial evidence for organic evolution, furnished by comparative anatomy, embryology and palæontology is cogent, we should be able to observe evolution going on at the present time, *i.e.*, we should be able to observe the occurrence of variations and their transmission. This has actually been done by the geneticist in the study of mutations and Mendelian heredity."

Delage and Goldsmith in their "Theories of Evolution" (1913) make the following statements:

"Two important phenomena mark the evolution of the organic world; one is the appearance of the different species, the differentiation of the various groups recognized in the classification of animals and plants, the increasing complexity of organisms, their evolution from the lowest to the highest forms; the other is the adaptation of living things to the conditions and necessities of their environment. The two processes, while simultaneous, differ entirely in their natures and are never superimposed."

Delage and Goldsmith are supporters of Lamarck's theory and therefore attach special importance to the transmission of characters acquired through environmental influences. Morgan may be looked upon as the most recent supporter of the natural selection theory, though his definition of "selection" is different from that given by Darwin. To the Lamarckian, adaptation to environment is of equal importance with evolution; to the selectionist, adaptation is the natural result of evolution. There is no question that animals have followed certain more or less arbitrary lines during their evolution on account of the inflexibility of

heredity and they have also shown increasing specialization to adapt them to environmental conditions. The Lamarckians maintain that animals acquire characters in their reactions to environment, that these are transmitted, and hence that changing environmental relations cause evolution and adaptation. Darwinians claim that there has been evolution because the environment has selected variations, and that there is adaptation because the variations which best fit the environment are selected. For the former view there is little or no evidence; for the latter there is increasing support from experiment and observation.

Professor Morgan in his recent book proposes a somewhat new method of selection as the basis of evolution. He believes that selection does not operate on small fluctuating variations but on numerous small mutations.

"Evolution of wild species appears to have taken place by modifying and improving bit by bit the structures and habits that the animal or plant already possessed. Evolution from this point of view has consisted largely in introducing new factors that influence characters already present in the animal or plant. . . . In other words, the emphasis may be placed less on the competition between the individuals of a species (because the destruction of the less fit does not *in itself* lead to anything that is new) than on the appearance of new characters and modifications of old characters that become incorporated in the species, for on these depends the evolution of the race.

"The mechanism of heredity has, I think, been discovered —discovered not by a flash of intuition but as the result of patient and careful study of the evidence itself. With the discovery of this mechanism I venture the opinion that the problem of heredity has been solved. We know how the factors carried by the parents are sorted out to the germ cells. The explanation does not pretend to state how factors arise or how they influence the development of the embryo. . . . So, I repeat, the mechanism of the chromo-

somes offers a satisfactory solution of the traditional problem of heredity."

There is perhaps some question as to whether hereditary characters may be modified by selection. That is, whether selection in a given direction may cause variation in the same direction. The bulk of the evidence, however, appears to indicate that such is not the case. According to Morgan, then:

"Evolution has taken place by the incorporation into the race of those mutations that are beneficial to the life and reproduction of the organism. Natural selection as here defined means both the increase in the number of individuals that results after a beneficial mutation has occurred (owing to the ability of living matter to propagate) and also that this preponderance of certain kinds of individuals in a population makes some further results more probable than others. More than this natural selection cannot mean, if factors are fixed and not changed by selection."

The question of evolution must be left in this state: the fact that there has been an evolution is proved, the methods by which evolution takes place have during the past few years become pretty well known, but the causes of variation and heredity are as yet largely unknown.

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